UNITED STATES DEPARTMENT OF AGRICULTURE
WAR FOOD ADMINISTRATION
Office of Marketing Services

RELATIONSHIPS BETWEEN PROPERTIES OF COTTON FIBERS AND STRENGTH OF CARDED YARNS

Preliminary Report

Washington, D. C.
March 1945

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SUMMARY AND CONCLUSIONS

Facts concerning the relationships of cotton fiber properties to manufacturing performance and to yarn and fabric quality are of value to and benefit both cotton agriculture and the textile industry in that: (1) They indicate to cotton breeders those fiber properties and combinations of fiber properties which should be incorporated in the new varieties and strains being developed; (2) they furnish breeders a ready means of determining the direction and extent of changes made in the fiber and spinning qualities of their progenies, and a basis for making their selections and rejections; (3) they are of assistance to agricultural leaders in the selection of varieties for one-variety and organized cotton communities; and (4) they aid spinners in selecting cottons needed for best results in the manufacture of various types of cotton goods.

Findings presented in this paper answer, in considerable part, such questions as: How much of the yarn strength variance is explainable by 8 separate and variously combined fiber properties? How closely can yarn strength be estimated or predicted from a knowledge of such fiber properties only? Which combination of fiber properties gives the best results? And which and how many fiber tests may be omitted from a series and still give sufficient data for satisfactorily predicting yarn strength?

The data used in these analyses represent 766 individually tested cottons covering a wide range of American Upland types as well as a wide range of growth conditions. Samples representing 16 commercial varieties, grown in duplicate at each of 8 locations across the rainfall part of the American Cotton Belt, during the crop years 1935, 1936, and 1937, have served as a basis of this study. All fiber, spinning, and yarn tests were performed by standardized methods under controlled atmospheric conditions.

By using multiple, partial, and simple correlation analyses, comprehensive studies have been made of the contribution of 8 cotton fiber properties, separately and in various combinations, to the skein strength of 22s and 60s carded yarn. The twists used in the manufacture of these

yarns are those which, in relation to the staple length of the raw cotton, give maximum yarn strength. The fiber properties included in the principal studies are upper quartile length, coefficient of length variability, strength, fineness, percentage of mature fibers and grade, and the relationships existing between 15 pairs of these have been determined. Mean fiber length and staple length have been considered in certain instances.

When the effects of the interrelated fiber properties measured are eliminated, 10 of the 15 pairs of 6 fiber properties are significantly correlated. The other 5 pairs of fiber properties possess little or no correlation. Appreciable scatter, however, is shown by all the pairs of fiber properties and the trend appears to be linear in every case. No indication of a curvilinear relationship has been noted for any pair of the fiber properties.

A coefficient of multiple linear correlation of 0.933 has been found for the relationship existing between the skein strength of 22s carded yarn and the 6 collective fiber properties mentioned; and 0.936 for that with 60s carded yarn. These correlations are considered relatively high.

The coefficient of determination is 0.871 for the 22s yarn and 0.875 for the 60s yarn. These statistical values indicate that 87 to 88 percent of the variance in the yarn skein strengths of these cottons is accounted for by the 6 fiber properties used in the analyses. These findings are viewed as being highly significant.

Almost as high a correlation has been found for the relationship between the skein strengths of either 22s or 60s yarn and the 4 collective fiber properties of upper quartile length, coefficient of length variability, fineness, and strength as was obtained with the 6 fiber properties.

With other combinations of fiber properties, the coefficients of correlation are appreciably less, the reductions varying with different combinations of fiber properties and being more or less proportionate to the number of fiber properties considered.

The results of simple correlation analyses indicate relative low or poor correlation between any one of the 8 fiber properties and yarn strength. Some of the respective fiber properties, however, are much better than others in this particular.

In terms of skein strength of 22s and 60s carded yarn, fiber strength is the most important of the 6 fiber properties considered; it is followed in turn by coefficient of length variability, upper quartile length, fineness expressed as weight per inch of fiber, grade, and percentage of mature fibers.

Although the rank of importance for the 6 fiber properties with respect to skein strength is the same for both 22s and 60s carded yarn, there is evidence that fiber length is somewhat more important to the strength of 60s yarn than to that of 22s, and that fiber strength is more important to the strength of 22s yarn than to that of 60s yarn. Whether the ranks obtained for the importance of fiber length and fiber strength to yarn strength would remain the same for counts much finer than 60s, or whether they would be reversed, is problematical.

When expressed in practical units of measure, as based on the six fiber-property equation, the average effect of change in each fiber property on the skein strength of 22s carded yarn, while the other fiber properties are held constant, has been found to be as follows: Lowering the grade of cotton by one grade, decreases yarn strength by 1.89 pounds; an increase of 1/32 inch in upper quartile length, increases yarn strength by 0.99 pound; an increase of 1 percent in the coefficient of length variability, decreases yarn strength by 1.94 pounds; an increase of one microgram per inch in weight of fiber, decreases yarn strength by 7.32 pounds (the coarser the fiber, the lower the yarn strength); an increase of 1 percent in the percentage of mature fibers decreases yarn strength by 0.26 pound; and an increase of 1,000 pounds per square inch in fiber strength, increases yarn strength by 0.94 pound.

Corresponding changes in the fiber properties cause more or less proportionate effects on the skein strength of 60s carded yarn.

The foregoing results, if expressed in another manner, show that an increase of 1 pound in the skein strength of 22s carded yarn results by: Raising the grade of cotton by 0.53 step; increasing the upper quartile length by 1/32 inch; decreasing the coefficient of length variability by 0.52 percent; decreasing fiber weight per inch by 0.14 microgram (the finer the fiber, the stronger the yarn); decreasing the percentage of mature fibers by 3.79 percent; or increasing fiber strength by 1,060 pounds per square inch.

The amount of change in the respective fiber properties necessary to cause an increase of 1 pound in yarn strength is from 2.0 to 3.4 times greater for 60s yarn than for 22s; however, on a relative basis, the amount of change in the fiber properties is from 1.2 to 2.3 times greater for 22s yarn than for 60s.

Sixty-six regression equations are presented which, by mathematically revealing the relation of the eight separate and variously combined fiber properties to the skein strength of 22s and 60s carded yarn, provide a tool for estimating directly the strength of those counts of yarn from only a knowledge of the magnitudes of the fiber properties. Supplemented by the use of a conversion formula, the equations also permit predictions of the skein strength of any count of carded yarn. The equations are, therefore, of value to cotton breeders, manufacturers,

and others who wish to predict the merits of a cotton in terms of the skein strength of carded yarn, without having to make a spinning test; or, in the event of a test, to compare the level of the results so obtained with the level representing the results furnished by the large number and wide range of carefully tested cottons used in this study.

Such equations will be of particular assistance to cotton breeders in their work in that they can now evaluate the yarn-strength merits of their new varieties and strains before large enough samples are available for the making of spinning and yarn tests. Thus, by the avoidance of several years' delay, with countless selections and hybrids, the cotton breeding work can be speeded up appreciably. Moreover, selections and rejections of new progenies can be made the "first year" with greater assurance than otherwise would be possible, thus enabling the breeders to concentrate only on the most promising strains and, thereby, to eliminate much unnecessary work, lost motion, and expense.

Estimated values of yarn strength derived by means of the equations listed should agree generally with the actual values obtained, within the limits of tolerance specified for each equation, provided certain conditions are satisfactorily met. There will, no doubt, be individual cases where actual and estimated values differ appreciably. In such instances, it is likely that either something is very unusual or extreme about one or more properties of the cotton, or else that the techniques, conditions, and specifications used by others in cotton yarn manufacture or in their fiber and yarn testing are appreciably different from those used in this study.

None of the equations involving the eight separate fiber properties gives estimates of yarn strength precise enough to put much reliance in results obtained on the basis of any one fiber property, alone. The greater the number of pertinent fiber properties included in an equation, the more reliable it will be for estimating yarn strength. Likewise, the more completely the interacting effects of other associated fiber properties are eliminated, the more significant will be the value obtained for the contribution or importance of any measured fiber property to yarn strength.

Both simple and partial correlation coefficients are presented as indicators of the importance of the respective fiber properties to yarn strength. Simple correlation coefficients, however, may be misleading as indicators of the "true" importance of separate fiber properties to yarn strength, because of certain interrelationships that exist among the fiber properties themselves. Simple correlation coefficients for the same reason, therefore, also may be misleading as a measure of the relationship between any pair of measured fiber properties.

Mean length appears to be a slightly better single statistical measure of fiber length distribution in relation to yarn strength than is upper quartile length alone. However, upper quartile length in conjunction with coefficient of length variability is a better measure of fiber length distribution in relation to yarn strength than is mean length alone.

No higher correlation or better results have been found between the six combined fiber properties and yarn-skein strengths by applying regular multiple curvilinear correlation analysis than by regular linear correlation technique. Improvement could hardly be expected by curvilinear analysis, however, since linear correlation between the collective fiber properties and yarn strength has shown the high multiple correlation coefficient reported.

Correlation analyses between the strength of 22s carded yarn and the product of fiber length by fiber strength as well as the product of these two factors divided by fiber fineness have given no better estimating equations than those obtained by the regular linear correlation analyses involving corresponding fiber properties.

In considering the statistical values and equations presented in this paper, it should be remembered that they refer only to American Upland cottons and only to skein strength of carded yarns. Findings from similar statistical studies using the same fiber data correlated with yarn appearance, with tire-cord strength, with tire-cord elongation, and with percentage of picker and card waste reveal a somewhat different picture with respect to over-all relationships and the relative importance of the different fiber properties. Those findings, however, are beyond the scope of this paper and will be presented in later reports of this series.

INTRODUCTION

Raw cottons vary greatly in their fiber properties and in certain other elements of quality. As a result, therefore, the spinning performance of individual cottons and mixes of cottons, and the quality of the products manufactured from them may vary greatly.

By origin and nature, cotton fibers possess a highly specialized and complicated type of structure. Most of their properties vary over relatively wide ranges, and many combinations of properties characterize them. It is these unique combinations and ranges of fiber structures and properties, plus the art of mixing and blending and the processes of spinning, weaving, and finishing, that have enabled cotton over the ages to meet so well its wide range of use and service requirements.

Much progress has been made during the last 30 years in the improvement of cotton fiber and spinning quality through the processes of breeding and selection, of better cultivation and harvesting, and of more efficient ginning. Progress also has been made during the same period in the standardization and classification of cotton with respect to quality as well as in the marketing, processing, and utilization of cotton.

Opportunities exist, however, for the development of still further improvements in cotton-fiber quality, in the standardization and marketing of cotton, and in the processing and utilization of cotton. Progress and success in many of these phases depend upon learning more precisely the relative importance of the separate and combined properties of the fibers in terms of spinning performance and of the quality of manufactured products.

More particularly, there is need for knowing the quantitative relationships which exist between cotton fiber properties and yarn skein strength as a means of answering such questions as: What combination of fiber properties is the most desirable from the standpoint of yarn strength? Which separate fiber property is the most important to yarn strength? Which one is the least important? What is the order of rank for the other contributing fiber properties? Is the order of importance of the separate fiber properties to yarn strength the same for coarse and fine yarns, or is it different? When comparisons are made of different cottons varying widely in staple length, on the basis of the yarn-strength data representing a count common to them all, are the short-staple varieties inadvertently favored and the long-staple ones penalized, or vice versa?

Similar questions also arise as to the relationships and importance of various separate and combined cotton fiber properties in the case of single strand strength, yarn appearance, tire-cord strength, cord elongation, percentage of picker and card waste, and other manufacturing qualities.

As an outgrowth of extensive fiber and spinning-testing activities over a number of years, the laboratories of the Office of Marketing Services have an accumulation of what is perhaps the largest and best volume of data on cotton fiber properties and spinning performance in existence. Comprehensive statistical analyses have been under way for some time, and are continuing, in an effort to establish the relationships of the various measureable fiber properties to manufacturing performance and to the quality of the manufactured product.

SAMPLES AND TEST PROCEDURES

The Federal-State South-wide regional variety study has furnished the basic data used in the statistical analyses reported in this paper. This study was designed primarily to provide data for studying the effect of variety, soil, season, and climate on the agronomic, fiber, and spinning properties that are important both from the agricultural and textile standpoints, in determining the spinning values of cotton. 1/

The 16 varieties of cotton that have been tested are listed in alphabetical order as follows:

Acala (Rogers)	Half and Half
Arkansas 17	Mexican Big Boll
Cleveland (Wannamaker)	Qualla
Cook 912	Rowden 40-2088
Delfos (Misdell) 4	Startex 619
Deltapine 11	Stoneville 5
Dixie Triumph 759	Triumph (Oklahoma) 44
Farm Relief 2	Wilds 5

Spinning test samples were obtained for each of the 16 varieties grown at each of the 8 locations listed as follows:

Florence, S. C.
Stoneville, Miss.
Marianna (Upland Station), Ark.
Marianna (Delta Station), Ark.
Baton Rouge, La.
Stillwater, Okla.
College Station, Tex.
Lubbock, Tex.

1/ The principal agencies cooperating in this study provided the samples and basic data involved, as well as assistance as follows: The Bureau of Plant Industry, Soils and Agricultural Engineering selected the varieties and growth locations, and produced and ginned all samples. The various Southern State experiment stations and substations cooperated in setting up the field work and in the production of the cottons. The Cotton and Fiber Branch of the Office of Marketing Services, laboratories of which are operated jointly with the Bureau of Plant Industry, Soils and Agricultural Engineering, the Agricultural and Mechanical College of Texas, and the Clemson Agricultural College of South Carolina, conducted the spinning and fiber tests.

For this phase of the study, duplicate lots of cotton - representing each variety and each location - were used for 3 consecutive crop years, namely 1935, 1936, and 1937. Such a plan provided 256 samples of cotton for spinning and companionate fiber tests from each crop year, or a total of 768 samples for the entire study. Fiber tests were made on the individual lots except in 4 instances. Two pairs of the corresponding lots of cotton were too small for individual spinning tests, as a result of growth conditions, so it was necessary to combine the duplicate lots and spin them as a single lot.

All the samples of seed cotton were ginned on a small 16-saw gin, without any preliminary cleaning or extracting action in the usually commercial ginning sense. The first and last portions of the lint from the gin were discarded, as the intervening material was considered more representative and best for fiber and spinning tests.

Lint samples were classified as to grade, staple length, and character by the U. S. Appeal Board of Review Examiners, according to the procedure, standards, and concepts described in Miscellaneous Publication 310 2/.

All fiber tests were carried out according to the standard routine procedures of the laboratories under atmospheric conditions of 65 percent relative humidity and 70°F. temperature, 3/ 4/, except that the fiber immaturity test with results expressed in "percentage of thin-walled fibers" has been replaced by the fiber maturity test with results expressed in "percentage of mature fibers." The latter is, however, a conversion figure obtained by subtracting the former from 100. With either test or basis of expression, a thin-wall fiber is one which, after treatment with a 18 percent caustic soda solution, is observed by means of microscopic examination to possess a wall thickness less than one-half of the width of the lumen or cavity within the fiber; and a mature fiber is one so treated and examined but whose wall thickness is equal to or greater than one-half of its lumen width. These methods are those currently used in the testing service work on cotton 5/.

2/ "The Classification of Cotton," prepared by the Bureau of Agricultural Economics, U.S.D.A.; Miscellaneous Publication 310; pages 1-54; May 1938. (The cotton standardization and classification work, a function of the Cotton and Fiber Branch, is now a part of Office of Marketing Services, War Food Administration.)

3/ "Methods for the Measurement of Certain Character Properties of Raw Cotton," by Howard B. Richardson, T.L.W. Bailey, Jr. and Carl M. Conrad, USDA, Tech. Bul. 545; pages 1-76; January 1937.

4/ "A.S.T.M. Standards on Textile Materials. Testing Cotton Fibers:" D414-40T; prepared by Committee D-13; pages 142-162; October 1943. (Published by the American Society for Testing Materials, Philadelphia, Pa., and issued annually.)

5/ "Cotton Fiber and Spinning Testing Service;" issued by Office of Distribution, WFA and USDA, Sept. 1944. (Processed.) Note: As a result of a recent reorganization, the service testing work is now a function of the Office of Marketing Services, WFA and USDA.

The spinning tests were performed with the technique developed in the laboratories of the Cotton and Fiber Branch for use with small samples of cotton. 5/ Each sample was passed successively through the following textile processing machines:

Finisher picker (twice)
Card
Drawing frame (twice)
Slubber
Intermediate
Fine frame
Regular draft spinning frame

At the spinning frame, each sample was spun into 3 numbers of carded yarn, including 22s; a fine number, such as 44s, 50s, or 60s, depending upon the staple length of the cotton; and an intermediate number such as 28s, 36s, or 44s.

The twist multipliers employed in the manufacture of these yarns were those giving maximum skein strengths for the particular staple lengths, as determined by an empirical formula developed in the laboratories of the Cotton and Fiber Branch. On the basis of the yarn construction used in general mill practice, those included in this study may be considered as having been medium-twist warp yarns.

Yarn twist multipliers in relation to staple length were used with these raw cottons, as follows: 5/8 inch, 5.35; 3/4 inch, 5.35; 25/32 inch, 5.15; 13/16 inch, 5.00; 27/32 inch, 4.85; 7/8 inch, 4.70; 29/32 inch, 4.60; 15/16 inch, 4.45; 31/32 inch, 4.35; 1 inch, 4.25; 1-1/32 inch, 4.20; 1-1/16 inch, 4.10; 1-3/32 inch, 4.05; 1-1/8 inch, 3.95; 1-5/32 inch, 3.90; 1-3/16 inch, 3.85; 1-7/32 inch, 3.80; 1-1/4 inch, 3.75; 1-9/32 inch, 3.70; 1-5/16 inch, 3.65.

Automatically controlled humidity and temperature were used in all card-room and spinning-room processes. The conditions were as follows: Card room, 60 percent relative humidity at 75°F.; spinning room 70 percent r.h. at 75°F. In the picker room where automatic control was not available, the cotton was processed under 45 to 55 percent r.h., but the temperature was not controlled.

Laboratory tests on the yarns were conducted in accordance with standard methods existing at the time, 6/, 7/, and under standard atmospheric conditions of 65 percent r.h. and 70°F.

6/ "A.S.T.M. Standards on Textile Materials." Testing and Tolerances for Cotton Yarns; D180-37; prepared by Committee D-13, pages 70-77; September 1937. (Published by the American Society for Testing Materials, Philadelphia, Pa., and issued annually.)

7/ "Standards for Appearance of Cotton Yarn," by Malcolm E. Campbell, Agricultural Marketing Service, U.S.D.A., pages 1-8; April 1940. (Processed.)

DATA USED IN STATISTICAL ANALYSES

For the purpose of simplification and convenience in presentation, grade is referred to herewith as a fiber property. Grade, however, is not a separate fiber property in the accepted technical sense of fiber length or fiber strength. More particularly, the grade designation of a sample of cotton represents a composite evaluation by cotton specialists, as based on three groups of factors, namely, color of fiber, foreign matter (amount and type of leaf and other extraneous matter), and "preparation" (the degree of smoothness with which the sample was ginned).

The basic fiber data pertaining to each cotton of the series, as derived from tests made on representative samples, constitute the following: Upper quartile length, mean length and coefficient of length variability, averages of data obtained from 3 or more length array tests made by the sorter method and expressed on a weight basis; fiber fineness expressed in micrograms per inch and percentage of mature fibers, averages of data obtained from 2 length arrays; fiber strength, as determined by the Chandler method - round wrapped bundle - and expressed in terms of 1,000 pounds per square inch of material, averages of 10 successful bundle breaks.

The classification data with respect to grade and staple length, were based on a single representative sample for each lot of cotton. This lint sampling procedure was considered adequate, since the samples of ginned lint were comparatively small and since the first and last portions of the ginned-lint bat were discarded in each instance.

That no cleaning and extracting processes were used in connection with the ginning of these cotton accounts, in part, for the fact that the ginned lint was, on the average, somewhat low in grade. In all probability, however, the reduction in grade from this cause was not over one-half of a grade step in the case of the lowest-grade samples and a lesser amount for the higher-grade samples.

Skein strength values obtained for each cotton represent an average of 25 individual tests for 22s yarn; 35 for 28s, 36s, and 44s; and 50 for 50s and 60s. The strengths have been adjusted to the specified count by the method described in Circular 413 8/, as exact counts of yarn are generally impossible to spin in any laboratory or cotton mill.

8/ An Improved Method for Converting an Observed Skein Strength of Cotton Yarn to the Strength of a Specified Yarn Count, by Malcolm E. Campbell, U. S. Department of Agriculture, Circular 413, October 1936.

In the statistical analyses, as reported here, the respective fiber, classification, and yarn data of duplicate lots of cottons, grown on duplicate field plots, have been averaged. Each average, with 2 exceptions, represents twice the number of fiber and yarn strength tests previously reported for each cotton. A total of 384 observations, representing 766 individually tested cottons, comprise the series.

Indiscriminate averaging of raw data for statistical analyses, as a general rule, is a dangerous procedure because interpretations and conclusions based on them frequently are in error and sometimes can be misleading. However, in this instance, no violence was done to the data by averaging them since duplicate samples and data were involved in all cases and since, in most instances, the respective data for the duplicate plots agreed very closely. In some cases, however, certain disparities did occur. The scatter of the observations with respect to a particular measure is, therefore, a little less for the 384 items than for the 766. Averaging the data in this manner reduced the amount of clerical work involved in the calculations by approximately one-half and this was a decided advantage.

In order to study the importance of various fiber properties of cotton with respect to their influence on the strength of yarn, or on any yarn and fabric quality, it is necessary that the data not only be reliable and comparable but that the fiber properties involved possess a range and frequency sufficiently great that there is an opportunity for their effects to be discernible in the correlation analyses. The extent to which the series of cottons used in this study varied in their fiber properties and in their skein strengths resulting from spinning each of them into 22s carded yarn of optimum twist for their respective staple lengths, is shown in table 1. Corresponding values also are shown in this table for the skein strength associated with 60s carded yarn, obtained from either direct measurement or conversion.

The data listed in table 1 show that, with the possible exception of grade and length, the fiber properties cover a relatively wide range. Even for grade and length, however, the ranges are greater than those of the bulk of American Upland cotton.

It is of interest to note the wide range of strength of 22s yarn furnished by these cottons, the weakest being 49 pounds per skein and the strongest 142 pounds, or a difference of 93 pounds per skein. This extremely wide range of yarn strengths is the result of the influence, over a comparatively wide range, of many combinations of fiber properties in the raw cottons from which the yarns were spun. In usual mill practice, the range of skein strengths for 22s yarn is substantially less than that obtained with this series of cottons, because cottons representing decidedly more restricted ranges of staple length, grade, and character are generally used in such cotton mixes of the textile industry.

Table 1. - Range and frequency of 8 measured fiber properties and of skein strengths for 22s and 60s carded yarns, used in multiple linear and simple correlation analyses, representing 384 averages of duplicate samples and 766 individually tested American Upland cottons, crop years 1935-37

Grade		Fiber length				Coef. length variability	
Grade number	Percent	Inches	Staple percent	Upper quartile percent	Mean percent	Percent	Percent
3.5- 4.4	0.5	0.50-0.59	------	-------	0.26	21-23	3.1
4.5- 5.4	20.0	.60- .69	0.26	-------	2.60	24-26	31.8
5.5- 6.4	41.4	.70- .79	2.60	0.5	12.50	27-29	34.9
6.5- 7.4	24.5	.80- .89	16.93	7.0	29.69	30-32	15.1
7.5- 8.4	6.5	.90- .99	48.70	13.0	36.46	33-35	9.9
8.5- 9.4	2.9	1.00-1.09	23.70	35.2	14.58	36-38	4.4
9.5-10.4	4.2	1.10-1.19	6.25	26.0	3.13	39-41	0.8
		1.20-1.29	1.30	13.3	0.78		
		1.30-1.39	0.26	3.7	------		
		1.40-1.49	------	1.3	------		
Mean	6.27		31/32	1.084	0.906		28.4
Maximum	10.00		1-5/16	1.45	1.23		40.0
Minimum	4.33		5/8	0.73	0.59		22.0

Fiber fineness		Mature fibers		Fiber strength		Yarn strength			
						22s count		60s count	
Micrograms per inch	Percent	Percent	Percent	1,000 pounds per sq. inch	Percent	Pounds per skein	Percent	Pounds per skein	Percent
2.7-3.1	0.5	48-52	1.0	58- 62	0.8	50- 59.9	2.3	0- 4.9	0.3
3.2-3.6	6.0	53-57	2.1	63- 67	3.9	60- 69.9	2.6	5- 9.9	1.5
3.7-4.1	13.3	58-62	7.6	68- 72	13.8	70- 79.9	6.5	10-14.9	7.3
4.2-4.6	24.5	63-67	12.8	73- 77	22.4	80- 89.9	17.7	15-19.9	18.0
4.7-5.1	30.7	68-72	19.5	78- 82	22.6	90- 99.9	32.8	20-24.9	40.3
5.2-5.6	18.5	73-77	34.9	83- 87	19.0	100-109.9	25.3	25-29.9	22.9
5.7-6.1	5.4	78-82	19.5	88- 92	12.0	110-119.9	7.3	30-34.9	6.0
6.2-6.6	0.8	83-87	2.6	93- 97	4.9	120-129.9	3.1	35-39.9	2.9
6.7-7.1	0.3			98-102	0.3	130-139.9	2.1	40-44.9	0.8
				103-107	0.3	140-149.9	0.3		
Mean	4.72		72.1		79.6		95.84		22.89
Maximum	6.9		86.0		103.0		142.0		43.0
Minimum	2.8		48.0		61.0		49.0		6.0

With respect to the strength of 60s yarn for the 384 lots of cotton in the series, data from actual tests were available for only 102 of them. In 282 cases, 60s yarn strength data were not available, since the staple lengths of those cottons were so short as to make difficult, if not sometimes impossible, the spinning of this count. Such being the case and in view of the fact that different lots of cottons, possessing different ranges and frequencies of fiber properties give different results, direct and valid comparisons between the findings from the 22s and 60s yarns are possible only if the frequencies and ranges of the magnitudes of the various fiber properties are common to both. It has been necessary, therefore, to use converted strengths of 60s yarn in the 282 instances where such were not available. These converted strengths were based on the highest count of yarn spun, namely, 50s, 44s or 36s, as the case may have been, using the formula developed in our laboratories. 9/

The strength of the 60s yarn spun from the 102 cottons ranged from 17.2 to 43.0 pounds per skein and averaged 28.22 pounds. For the entire series of 384 cottons, however, where both converted and actual values were involved, the yarn strength ranged from 6.0 to 43.0 pounds per skein with an average of 22.89 pounds. The strength of the 60s yarn actually spun and tested, therefore, averaged 5.33 pounds per skein more than did that for the entire series when both converted and actual values were included.

In general mill practice, the range of skein strengths for 60s yarn is usually less than that obtained with the series of cottons here considered, for the reasons previously stated in connection with 22s and 60s yarns. The average level of the strength of such 60s yarn from commercial manufacture probably would approximate 30.0 pounds per skein. Thus, the mean value obtained for the entire series of cottons used in this study, including both actual and converted strength values for 60s yarn is substantially less than that associated with commercial yarns of this type and count. However, the mean strength of the 60s yarn actually spun from the 102 cottons, which were long enough to be spun satisfactorily into this count of yarn, is in general line with the average strength of 60s yarn produced in commercial manufacture.

ANALYSES OF DATA

An effort has been made in this report to present and interpret the results in such a way that those who are not familiar with such statistical methods and values may be able to understand the equations, findings, and discussion. Effort also has been made to emphasize the limitations of the various methods and measures that have been applied no less than their possibilities.

9/ See footnote 8/, page 10.

A knowledge of the various statistical terms and measures used in the present studies is desirable, although not necessary for a general understanding of this presentation. For convenience and ready reference, however, brief descriptions of the more pertinent and important items are given in the Appendix.

For complete description of the methods, terms, symbols, and measures employed in these analyses, reference may be had to one or more of the generally available statistical texts, such as those listed in the Appendix.

CORRELATION BETWEEN VARIOUS PAIRS OF FIBER PROPERTIES

Although the principal purpose of the present paper is to study the contribution and importance of various fiber properties towards the strength of 22s and 60s yarn, some of the correlations are influenced by certain fiber properties being correlated with each other. A study has, therefore, first been made of the simple correlations between all possible pairs of 6 of the fiber properties considered, or a total of 15 combinations.

Simple correlations. The results presented in table 2 show that, with this group of cottons, the highest simple correlation occurs between grade of cotton and the coefficient of length variability, followed in order by the other pairs of fiber properties listed. A correlation coefficient above 0.60 is considered significant and below 0.60 of little or no significance. On this basis, it would appear that the first 3 of the correlations are significant and that the remaining 12 are of little or negligible significance.

In general, the simple correlation coefficients are too low and the standard errors of estimate are too large to conclude that any one of the measured fiber properties is closely associated with any other fiber property, or that one may estimate very accurately the magnitude of a fiber property by measuring another one. However, the associations are of particular interest to cotton breeders who wish to know whether an improvement in one fiber property is likely to be accompanied by an improvement or a deterioration in some other fiber property.

Scatter diagrams representing the data for each of the 15 pairs of fiber properties reveal a wide scatter for all the pairs and indicate a linear trend in every instance. No suggestion of a curvilinear relationship has been observed with any of the pairs of fiber properties studied.

Partial correlations. Simple correlations between cotton fiber properties are affected somewhat by the fact that several fiber properties generally are correlated with or interacting upon each other. Thus, the coefficients of simple correlation should be looked upon, in this instance, as referring more particularly to the apparent relationships

Table 2. - Rank of simple correlation between all possible pairs of 6 measured fiber properties, representing 384 averages of duplicate samples and 766 individually tested American Upland cottons, crop years 1935-37

Rank	Fiber properties correlated	Coefficient of correlation (r)	Coefficient of determination (r^2)	Standard error of estimate 1/ (S)
1	Grade of cotton with coef. of length variability	+ 0.627 ± .031	0.393 ± .039	± 0.92
2	Fiber weight per inch with percent of mature fibers	+ .611 ± .032	.373 ± .039	± .52
3	Upper quartile length with fiber weight per inch	- .603 ± .032	.364 ± .039	± .10
4	Coef. of length var. with percent of mature fibers	- .572 ± .034	.327 ± .039	± 3.02
5	Fiber weight per inch with fiber strength	- .426 ± .042	.181 ± .036	± .59
6	Coef. of length variability with fiber weight per inch	- .377 ± .044	.142 ± .033	± 3.41
7	Grade of cotton with percent of mature fibers	- .321 ± .046	.103 ± .030	± 1.12
8	Percent of mature fibers with fiber strength	- .287 ± .047	.082 ± .027	± 6.49
9	Grade of cotton with upper quartile length	- .225 ± .048	.051 ± .022	± 1.15
10	Grade of cotton with fiber weight per inch	- .225 ± .048	.051 ± .022	± 1.15
11	Upper quartile length with coef. of length variability	- .120 ± .050	.014 ± .012	± .12
12	Upper quartile length with fiber strength	+ .089 ± .051	.008 ± .009	± .12
13	Coef. of length variability with fiber strength	+ .088 ± .051	.008 ± .009	± 3.66
14	Upper quartile length with percent of mature fibers	- .058 ± .051	.003 ± .006	± .12
15	Grade of cotton with fiber strength	+ .034 ± .051	.001 ± .003	± 1.18

1/ Standard errors are expressed in terms of the fiber property used as the dependent variable, which is the first fiber property listed on each line under the heading "Fiber properties correlated."

existing between the various pairs of fiber properties rather than to the true relationships occurring between them. Although the coefficients of simple correlation reported possess limitations, they are of interest in that they suggest what to expect when any 2 of the fiber properties are considered alone, and how misleading they can be when the effects of the interrelated and interacting fiber properties are disregarded.

In order to determine the true correlation between each pair of the 6 fiber properties considered, that is, the relationship after eliminating the effect of all other measured fiber properties, the partial correlation coefficients have been determined. The findings obtained are shown in table 3, the 15 pairs of fiber properties being listed in the order of their descending coefficients of partial correlation.

Several interesting facts are revealed by the partial correlation coefficients. In the light of the standard errors, it would appear that 10 pairs of the fiber properties are significantly correlated whereas 5 of the pairs possess little or no correlation. Upper quartile length and fiber weight per inch show the highest degree of correlation and the next 9 pairs of fiber properties showing significant correlation are ranked in order as follows: Fiber weight fineness with percent of mature fibers, grade of cotton with coefficient of length variability, fineness with tensile strength, upper quartile length with percent of mature fibers, coefficient of length variability with percent of mature fibers, upper quartile length with fiber strength, grade of cotton with upper quartile length, grade of cotton with weight per inch, and grade of cotton with percent of mature fibers.

It should be noted that the partial correlation between upper quartile length and fiber fineness is the highest shown by the 15 pairs of fiber properties considered, whereas the simple correlation for this pair of fiber properties ranks third. Other significant changes may be noted as follows: Upper quartile length with percent of mature fibers now ranks fifth, as compared with its former rank of fourteenth; upper quartile length with fiber strength is now seventh, as compared with its former twelfth position; grade of cotton with percent of mature fibers is now tenth, as compared with its former seventh position; coefficient of length variability with weight per inch is now eleventh, whereas formerly it was sixth; and percent of mature fibers with fiber strength is now fifteenth, whereas formerly it was eighth.

The foregoing gives evidence of the necessity for exercising extreme caution when attempting to draw conclusions with respect to relationships between cotton fiber properties on the basis of simple coefficients of correlation, when standing by themselves.

MULTIPLE LINEAR CORRELATION BETWEEN YARN SKEIN STRENGTH AND VARIOUS COMBINATIONS OF FIBER PROPERTIES

One of the items of particular interest and importance to be revealed by correlation analyses in studies of cotton quality is that of the quantitative relation of various fiber properties, acting separately

Table 3. - Rank of partial correlation between all possible pairs of 6 measured fiber properties, representing 384 averages of duplicate samples and 766 individually tested American Upland cottons, crop years 1935-37

Rank		Fiber properties correlated	Coefficient of partial correlation, $r_{24.1356}$, etc.	Standard error of $r_{24.1356}$, etc.
1	(3) 1/	Upper quartile length with fiber weight per inch	− 0.785	± 0.020
2	(2)	Fiber weight per inch with percent of mature fibers	+ .556	± .035
3	(1)	Grade of cotton with coefficient of length variability	+ .487	± .039
4	(5)	Fiber weight per inch with fiber strength	− .449	± .041
5	(14)	Upper quartile length with percent of mature fibers	+ .372	± .044
6	(4)	Coef. of length variability with percent of mature fibers	− .334	± .045
7	(12)	Upper quartile length with fiber strength	− .320	± .046
8	(9)	Grade of cotton with upper quartile length	− .317	± .046
9	(10)	Grade of cotton with fiber weight per inch	− .262	± .048
10	(7)	Grade of cotton with percent of mature fibers	+ .169	± .050
11	(6)	Coef. of length variability with fiber weight per inch	− .143	± .050
12	(11)	Upper quartile length with coef. of length variability	− .140	± .050
13	(13)	Coef. of length variability with fiber strength	− .127	± .050
14	(15)	Grade of cotton with fiber strength	− .117	± .050
15	(8)	Percent of mature fibers with fiber strength	+ .042	± .051

1/ Figures in parenthesis refer to order of rank, as based on simple correlation.

and in combination, to the strength of the yarn. Such correlation analyses provide various statistical measures. Of these statistical measures, the regression coefficients, together with a constant term, furnish equations from which estimated yarn strengths may be obtained when the magnitude of the various fiber properties are known. Some of these equations furnish estimates that are more precise than others, as indicated by the magnitude of the standard errors. The latter vary according to the number and nature of the fiber properties involved, that is, the smaller the magnitude of the standard error, the closer is the estimated yarn strength to the actual.

In connection with fiber-yarn relationships, the results from analyses made to date indicate that the closest and best estimates of the skein strength of both 22s and 60s carded yarn are obtained by measuring 6 fiber properties and substituting these values in the appropriate regression equation. Such a procedure should be used if the highest degree of precision is desired. However, some of the fiber properties are not so important as others with respect to strength of yarn and frequently the cost of making all 6 fiber tests is prohibitive. Too, in many cases, only a general idea of the estimated yarn strength is needed. For these reasons, therefore, it is desirable to know what and how many fiber-property tests may be omitted from those here included and, at the same time, still give sufficient data for estimating or predicting yarn strength with practical satisfaction, the degree of which varies for different purposes.

The multiple regression equations that have been developed, representing six fiber properties, will be considered first, followed in order by the equations representing certain combinations of five, four, three, and two fiber properties. These equations are listed in table 4, and are ranked according to their decreasing coefficients of correlation and increasing standard errors of estimate. The coefficients of determination also are shown in the tabulation as well as the standard errors associated with the different coefficients.

(22s Yarn)

Six fiber properties. A multiple regression equation has been derived by correlating the strength of 22s carded yarn with the six fiber properties of grade, upper quartile length, coefficient of length variability, fineness in micrograms per inch, percent of mature fibers, and fiber tensile strength. A corresponding regression equation has been developed for the same fiber properties, except that mean fiber length has been substituted for upper quartile length.

Referring to equations (1) and (2), as shown in table 4, it is interesting to note the very close agreement between the two. Aside from the constant term, the widest difference appears to be between the coefficients of X_2 and X_{11}, namely, of upper quartile length and mean length.

Table 4. - Summary of regression equations and statistical values showing the relation between the skein strength of 22s carded yarn and eight separate and variously combined fiber properties, ranked according to decreasing coefficients of correlation and increasing standard errors, as based on multiple linear or simple correlation analyses of 384 averages of duplicate samples, representing 766 individually tested American Upland cottons, crop years 1935-37

Identification			Regression equations involving										Statistical values		
				Coefficients for independent variables of											
			(X_8')	(X_1)	(X_2)	(X_{10})	(X_{11})	(X_3)	(X_4)	(X_{35})	(X_6)	(A)	(S)	($\bar{R}$, r)	($\bar{R}^2$, r^2)
Number	Rank	Fiber properties	Estimated strength, 22s yarn, pounds per skein	Grade of cotton, by number	Upper quartile length, in inches	Staple length, in inches	Mean length, in inches	Coefficient of length variability, in percent	Fiber fineness, in micrograms per inch	Percentage of mature fibers	Fiber tensile strength, in 1000 pounds per square inch	Constant	Standard error of estimate, in pounds per skein	Coefficient of correlation	Coefficient of determination
(1)	1	6	X_8' =	- 1.856	------	------	+ 39.737	- 1.693	- 7.189	- 0.271	+ 0.942	+ 98.12	± 5.36	0.935 ± .006	0.873 ± .011
(2)	2	6	X_8' =	- 1.894	+ 31.836	------	------	- 1.939	- 7.318	- .264	+ .942	+106.85	± 5.42	.933 ± .007	.871 ± .013
(3)	3	5	X_8' =	- 2.119	+ 25.954	------	------	- 1.781	- 9.455	------	+ .935	+101.80	± 5.55	.930 ± .007	.865 ± .013
(4)	4	5	X_8' =	------	+ 38.975	------	------	- 2.268	- 5.884	- .328	+ .972	+ 92.09	± 5.67	.927 ± .007	.859 ± .012
(11)	5	4	X_8' =	------	+ 32.546	------	------	- 2.115	- 8.395	------	+ .967	+ 83.29	± 5.85	.922 ± .008	.849 ± .015
(5)	6	5	X_8' =	- 1.230	+ 55.457	------	------	- 1.810	------	- .544	+ 1.094	+ 46.96	± 5.86	.922 ± .008	.849 ± .015
(6)	7	5	X_8' =	- 2.744	------	------	------	- 2.073	- 13.398	- .066	+ .828	+174.09	± 5.91	.920 ± .008	.847 ± .017
(14)	8	3	X_8' =	------	+ 60.398	------	------	- 1.485	------	------	+ 1.205	- 23.47	± 6.63	.898 ± .010	.807 ± .018
(7)	9	5	X_8' =	- 3.609	------	------	+ 62.063	------	- 3.303	- .061	+ 1.052	- 1.49	± 6.64	.898 ± .010	.806 ± .018
(8)	10	5	X_8' =	- 4.544	+ 40.910	------	------	------	- 5.075	+ .097	+ 1.034	+ 14.58	± 7.20	.879 ± .012	.772 ± .021
(9)	11	5	X_8' =	- 4.488	------	+ 52.859	------	------	- 5.496	+ .118	+ 1.036	+ 8.06	± 7.20	.879 ± .012	.772 ± .021
(18)	12	2	X_8' =	------	------	------	+ 84.990	------	------	------	+ 1.146	- 72.40	± 7.49	.868 ± .013	.754 ± .023
(12)	13	4	X_8' =	- 5.899	------	------	------	------	- 12.840	+ .389	+ .892	+ 94.39	± 7.81	.855 ± .014	.732 ± .024
(10)	14	5	X_8' =	- 2.718	+ 5.000	------	------	- 2.258	- 16.462	- .205	------	+264.16	± 8.20	.839 ± .015	.705 ± .025
(13)	15	4	X_8' =	- 2.888	+ 0.587	------	------	- 2.132	- 18.069	------	------	+259.27	± 8.25	.837 ± .015	.701 ± .021
(15)	16	3	X_8' =	------	+ 70.718	------	------	------	+ 1.514	------	+ 1.182	- 82.11	± 8.52	.825 ± .016	.681 ± .026
(21)	17	2	X_8' =	------	+ 66.135	------	------	------	------	------	+ 1.134	- 66.23	± 8.54	.824 ± .016	.679 ± .026
(22)	18	2	X_8' =	------	------	------	------	- 1.746	------	------	+ 1.302	+ 41.74	± 9.89	.755 ± .022	.570 ± .033
(17)	19	3	X_8' =	- 1.400	+ 65.918	------	------	- .960	------	------	------	+ 60.38	± 11.23	.667 ± .028	.445 ± .037
(23)	20	2	X_8' =	------	+ 67.959	------	------	- 1.233	------	------	------	+ 57.20	± 11.30	.662 ± .029	.438 ± .038
(26)	21	1	X_8' =	------	------	------	+ 90.642	------	------	------	------	+ 13.76	± 11.53	+ .645 ± .030	.416 ± .039
(24)	22	2	X_8' =	- 3.288	+ 65.289	------	------	------	------	------	------	+ 45.62	± 11.57	.642 ± .030	.412 ± .039
(25)	23	2	X_8' =	- 3.157	------	+ 85.398	------	------	------	------	------	+ 33.40	± 11.67	.633 ± .031	.400 ± .039
(27)	24	1	X_8' =	------	------	------	------	------	------	------	+ 1.228	- 1.95	± 11.78	+ .624 ± .031	.390 ± .039
(28)	25	1	X_8' =	------	+ 72.397	------	------	------	------	------	------	+ 17.35	± 12.17	+ .591 ± .033	.349 ± .039
(29)	26	1	X_8' =	------	------	+ 95.413	------	------	------	------	------	+ 4.07	± 12.22	+ .586 ± .033	.343 ± .039
(30)	27	1	X_8' =	------	------	------	------	------	- 12.434	------	------	+154.58	± 12.71	- .539 ± .036	.290 ± .039
(31)	28	1	X_8' =	- 4.820	------	------	------	------	------	------	------	+126.07	± 13.96	- .378 ± .044	.143 ± .033
(32)	29	1	X_8' =	------	------	------	------	- 1.507	------	------	------	+138.65	± 14.02	- .368 ± .044	.135 ± .032
(33)	30	1	X_8' =	------	------	------	------	------	------	- .327	------	+119.42	± 14.92	- .147 ± .050	.022 ± .015
(34)	31	0	X_8' =	------	------	------	------	------	------	------	------	+ 95.84	± 15.08	------------	------------

This difference is logical and explainable, however, by the fact that the mean length of a sample is generally about 15 to 25 percent shorter than its upper quartile length. It should be noted that the two equations possess reliability of practically the same high order, the standard error of estimate (S) being only $\pm$ 5.36 pounds in the case of equation (1) where mean length was used and $\pm$ 5.42 pounds in the case of equation (2) with upper quartile length.

Briefly, the values listed for the standard errors of estimate mean that, by using equation (1), two-thirds of the estimated values for strength of 22s yarn would, on the average, fall within $\pm$ 5.36 pounds of the actual yarn strength. Or by using equation (2), two-thirds of the estimated values would be expected to occur within $\pm$ 5.42 pounds of the actual.

The coefficient of multiple linear correlation (R) derived from using the six fiber properties in equation (1) is 0.935 $\pm$ 0.006. This correlation is considered relatively high, since perhaps not all the fiber properties involved in yarn strength have been included in this study and since some errors of sampling and measurement are unavoidable even with the best techniques available for the measurement of each and every fiber and yarn property considered. Squaring the figure for the coefficient of correlation, a figure of 0.873 is obtained for the coefficient of determination (R^2). This indicates that 87 percent of the variance in the yarn strength of these cottons is accounted for by the 6 fiber properties used in the analysis, a fact which seems highly significant.

Referring to equation (2), where the values for upper quartile length are used instead of mean length as in equation (1), R = 0.933 $\pm$ 0.007 and R^2 is computed as 0.871. Thus, 87 percent of the variance in yarn strength is explainable by the 6 fiber properties considered when upper quartile length was used, or the same amount as when mean length was used.

<u>Five fiber properties.</u> Correlation between 8 combinations of 5 fiber properties and strength of 22s yarn give interesting results. The equations are based on direct multiple correlation between the variables involved and are shown in table 4, as equations (3), (4), (5), (6), (7), (8), (9), and (10).

Comparing equations (3) with equation (2), listed under six fiber properties, it is seen that the omission of the percentage of mature fibers from the analysis causes an increase in the standard error of estimate of only $\pm$ 0.13 pounds, the respective standard errors being $\pm$ 5.55 and $\pm$ 5.42. This indicates that, insofar as the effect of the percentage of mature fibers on the strength of 22s yarn is concerned, this fiber property is of little or no importance; that is, it is unimportant within the range of values obtained for this series of cottons by the method of test employed. The findings also suggest that it is not necessary to make the test for the percentage of mature fibers unless the effect of this property on other manufacturing properties, such as yarn

appearance, waste, or spinnability of the cotton, is desired. Similar comparisons can be made of all other equations, and respective conclusions reached.

The foregoing studies, where each of the 6 fiber properties are omitted in turn, reveal in a practical way the importance of the various fiber properties. In judging the importance of each fiber property by the increased standard error that results when each is omitted, fiber strength is first in importance. This is followed in order by coefficient of variability of length, upper quartile length, fineness, grade of cotton, and percentage of mature fibers. The effect of fiber strength appears to be even greater than the combined effect of upper quartile length and coefficient of length variability, as is revealed when both of these fiber properties are omitted. Specifically, when fiber strength alone is omitted, the standard error increases by $\pm$ 2.78 pounds and when both upper quartile length and coefficient of length variability are omitted, the standard error increases by $\pm$ 2.39 pounds.

Four fiber properties. Correlation between 3 different combinations of 4 fiber properties and strength of 22s yarn have given equations (11), (12), and (13), as shown in table 4.

In equation (11), the grade of the cotton and the percentage of mature fibers have been omitted as independent variables. The standard error of estimate is $\pm$ 5.85, which differs from that for the six-fiber-property equation (2) by only $\pm$ 0.43 pound, the standard error for the equation with the 6 fiber properties being $\pm$ 5.42. Thus, almost as high a precision was obtained in estimating the strength of 22s yarn from the 4 fiber properties of upper quartile length, coefficient of length variability, fineness, and strength as was obtained with the 6 fiber properties.

The conclusion referred to above is confirmed by the statistical measures obtained with the six-fiber and four-fiber property equations, respectively, as follows: $R = 0.933$ and 0.922; $R^2 = 0.871$ and 0.849. In other words, 87 percent of the variation in yarn strength is explainable on the basis of the 6 fiber properties measured, whereas 85 percent of the yarn-strength variation is accounted for by the 4 fiber properties mentioned. These are very significant findings, since a difference of only 2 percent is small for matters of this kind. Hence, if only the strength of 22s yarn is concerned and if only the estimated strength of 22s yarn is desired, apparently very little is to be gained by including the factors of grade and the percentage of mature fibers.

Three fiber properties. Several different combinations of 3 fiber properties were next studied. These equations are identified as (14), (15), and (17) in table 4.

Equation (14) contains upper quartile length, coefficient of length variability, and fiber strength and omits grade of cotton, fineness and percentage of mature fibers. The omission of these fiber properties results in a standard error of $\pm$ 6.63 pounds, as compared with

$\pm$ 5.42 pounds for equation (2) where values of all 6 fiber properties are used. This is a difference of $\pm$ 1.21 pounds. For some purposes, the estimate may be considered sufficiently close.

In equation (15), grade of cotton, coefficient of length variability, and percentage of mature fibers were omitted. The size of the standard error of estimate by this equation indicates a considerable loss in precision, as only 68 percent of the yarn strength is accounted for on the basis of the 3 fiber properties considered, namely, upper quartile length, fineness, and strength. Most of this disparity is attributable to omitting coefficient of length variability from the equation.

In an equation not listed in table 4, the same fiber properties as in equation (15) were used; however, in this instance, the products of the upper quartile lengths and fiber strengths were divided by fineness. The quotients so obtained were used as a single independent variable and correlated with the strength of 22s yarn. It was thought that this procedure might furnish an equation that would give a better fit to the data than linear correlation. However, the standard error of estimate by this "product-division" equation is greater than that for equation (15) which includes the same fiber properties correlated by linear correlation methods; or 54 percent of the yarn-strength variability is accounted for in the "product-division" equation, as compared with 68 percent in equation (15). Apparently, the explanation for these disparities lies in the fact that length and fineness are correlated, or that the relationship assumed in the equation is not applicable. In any event, nothing was gained by using the fiber properties in this form of an equation.

Two fiber properties. Eight equations were derived involving 2 fiber properties. Six of these are listed in table 4 as equations (18), (21), (22), (23), (24), and (25).

Equation (18) involves the fiber properties of mean length and fiber strength, derived directly from multiple correlation analysis, whereas the unlisted equation (19) was derived by simple correlation analysis in which the products of these 2 fiber properties were used as the independent variable. The latter method was tried out since it was thought possible that, by doing so, a higher correlation and a lower standard error might result. However, on a basis of the standard errors, nothing was gained by this method. This conclusion is confirmed by similar results obtained from a pair of equations where upper quartile length replaces mean length in both cases. The R and R^2 values for the respective pairs of equations, also, are essentially identical.

Considering the above equations from the standpoint of their merits, and skipping the equations which involve products of certain fiber properties, the following conclusions may be drawn: Equation (18), involving mean length and fiber strength, results in a standard error of $\pm$ 7.49 pounds as compared with $\pm$ 5.36 pounds for the equation (1) with the 6 fiber properties, or a difference of only $\pm$ 2.13 pounds. It thus appears

that, for some purposes, mean length and fiber strength would be the only fiber properties necessary to measure, if only the estimated strength of 22s yarn is desired within the limits indicated. The R and R^2 values of this analysis are 0.868 and 0.754, respectively, the latter value indicating that 75 percent of the yarn strength variance is accounted for by only two fiber properties, namely, mean length and strength.

Equation (25) is of particular interest since it was derived on the basis of grade and staple length, 2 nonlaboratory measurements for which official cotton standards are available. Using these 2 measures, the results show that the strength of 22s yarn can be estimated in two-thirds of the cases on the average within $\pm$ 11.67 pounds or $\pm$ 12 percent of the mean yarn strength. This estimate compares with $\pm$ 11.57 pounds with equation (24) where upper quartile length replaces staple length. Thus, on a basis of grade and staple length, 40 percent of the yarn strength variance is accounted for whereas, in the case of grade and upper quartile length, 41 percent is explainable. This comparison is based on the R^2 values for the respective equations.

The findings in reference to grade and staple length probably possess even more significance in actual mill practice than would appear at face value, because of the fact that it is customary for the management of individual mills to select their cottons within relatively narrow ranges of grade and staple length, in many cases from one-variety or organized cotton communities, and always to mix a number of bales for each run or blend of cotton. By this procedure, the law of averages enters into the matter from the standpoint not only of grade and staple length but also of other accompanying fiber properties. It is reasonable to expect, therefore, that the range and frequency of fluctuations would be reduced and that the estimated and actual yarn strength values would show better agreement in the case of cotton mixes than of individual cottons.

(60s Yarn)

Six fiber properties. As was done in the case of 22s yarn, a multiple regression equation has been developed by correlating the strength of 60s carded yarn with the six properties of grade, upper quartile length, coefficient of length variability, fiber fineness, percentage of mature fibers, and fiber tensile strength. A corresponding regression equation has been developed, except that mean fiber length has been substituted for upper quartile length.

The 2 six-fiber property equations (35) and (36), as well as those involving fewer fiber properties, are ranked in table 5 according to their decreasing coefficients of correlation and increasing standard errors of estimate. The coefficients of determination and the standard errors associated with the two sets of coefficients also are shown in the tabulation.

Table 5. - Summary of regression equations and statistical values showing the relation between the skein strength of 60s carded yarn and 8 separate and variously combined fiber properties, ranked according to decreasing coefficients of correlation and increasing standard errors, as based on multiple linear or simple correlation analyses of 384 averages of duplicate samples, representing 766 individually tested American Upland cottons, crop years 1935-37.

Identification			Regression equations involving										Statistical values		
				Coefficients for independent variables of											
Number	Rank	Fiber properties	(X'_{16}) Estimated strength, 60s yarn, pounds per skein	(X_1) Grade of cotton, by number	(X_2) Upper quartile length, in inches	(X_{10}) Staple length, in inches	(X_{11}) Mean length, in inches	(X_3) Coefficient of length variability, in percent	(X_4) Fiber fineness, in micrograms per inch	(X_{35}) Percentage of mature fibers	(X_6) Fiber tensile strength, in 1000 pounds per square inch	(A) Constant	(S) Standard error of estimate, in pounds per skein	(R, r) Coefficient of correlation	(R^2, r^2) Coefficient of determination
(35)	1	6	X'_{16} =	- 0.775	------	------	+ 21.333	- 0.558	- 3.211	- 0.147	+ 0.274	+ 28.24	± 2.09	0.937 ± .006	0.878 ± .011
(36)	2	6	X'_{16} =	- .783	+ 17.544	------	------	- .688	- 3.193	- .146	+ .276	+ 31.97	± 2.12	.936 ± .006	.875 ± .011
(37)	3	5	X'_{16} =	- .907	+ 14.297	------	------	- .601	- 4.373	------	+ .272	+ 29.15	± 2.21	.929 ± .007	.864 ± .013
(38)	4	5	X'_{16} =	------	+ 20.497	------	------	- .824	- 2.600	- .172	+ .288	+ 25.80	± 2.23	.929 ± .007	.862 ± .013
(39)	5	5	X'_{16} =	- .494	+ 27.851	------	------	- .632	------	- .268	+ .342	+ 5.81	± 2.33	.922 ± .008	.849 ± .015
(45)	6	4	X'_{16} =	------	+ 17.120	------	------	- .744	- 3.919	------	+ .286	+ 21.24	± 2.35	.920 ± .008	.846 ± .014
(40)	7	5	X'_{16} =	- 1.353	------	------	+ 28.693	------	- 1.930	- .077	+ .310	- 4.67	± 2.46	.912 ± .009	.832 ± .016
(41)	8	5	X'_{16} =	- 1.252	------	------	------	- .762	- 6.544	- .037	+ .213	+ 69.03	± 2.48	.911 ± .009	.829 ± .016
(42)	9	5	X'_{16} =	- 1.724	+ 20.765	------	------	------	- 2.397	- .018	+ .309	- 0.77	± 2.71	.893 ± .010	.797 ± .020
(43)	10	5	X'_{16} =	- 1.729	------	+ 25.589	------	------	- 2.783	- .001	+ .306	- 2.06	± 2.75	.889 ± .011	.791 ± .020
(48)	11	3	X'_{16} =	------	+ 30.122	------	------	- .450	------	------	+ .397	- 28.58	± 2.77	.887 ± .011	.787 ± .020
(44)	12	5	X'_{16} =	- 1.025	+ 9.680	------	------	- .782	- 5.873	- .129	------	+ 78.09	± 2.78	.886 ± .011	.785 ± .019
(46)	13	4	X'_{16} =	- 1.131	+ 6.916	------	------	- .703	- 6.879	------	------	+ 74.97	± 2.84	.881 ± .011	.776 ± .019
(51)	14	2	X'_{16} =	------	------	------	+ 38.910	------	------	------	+ .383	- 42.85	± 2.87	.878 ± .012	.771 ± .021
(47)	15	4	X'_{16} =	- 2.412	------	------	------	------	- 6.339	+ .131	+ .237	+ 39.66	± 3.11	.855 ± .014	.731 ± .024
(49)	16	3	X'_{16} =	------	+ 30.550	------	------	------	- .433	------	+ .361	- 36.97	± 3.21	.845 ± .015	.714 ± .025
(52)	17	2	X'_{16} =	------	+ 31.860	------	------	------	------	------	+ .375	- 41.54	± 3.21	.844 ± .015	.713 ± .025
(50)	18	3	X'_{16} =	- .565	+ 31.789	------	------	- .257	------	------	------	- 0.74	± 4.06	.736 ± .023	.542 ± .034
(53)	19	2	X'_{16} =	------	+ 32.612	------	------	- .367	------	------	------	- 2.04	± 4.09	.731 ± .024	.535 ± .035
(57)	20	1	X'_{16} =	------	------	------	+ 40.800	------	------	------	------	- 14.05	± 4.10	+ .730 ± .024	.533 ± .035
(54)	21	2	X'_{16} =	- 1.070	+ 31.621	------	------	------	------	------	------	- 4.68	± 4.13	.726 ± .024	.527 ± .035
(55)	22	2	X'_{16} =	- 1.011	------	+ 41.099	------	------	------	------	------	- 10.35	± 4.22	.710 ± .025	.505 ± .036
(58)	23	1	X'_{16} =	------	+ 33.933	------	------	------	------	------	------	- 13.90	± 4.31	+ .696 ± .026	.484 ± .036
(59)	24	1	X'_{16} =	------	------	+ 44.307	------	------	------	------	------	- 19.78	± 4.38	+ .684 ± .027	.467 ± .037
(56)	25	2	X'_{16} =	------	------	------	------	- .580	------	------	+ .445	+ 3.92	± 4.59	.644 ± .030	.415 ± .039
(60)	26	1	X'_{16} =	------	------	------	------	------	- 5.713	------	------	+ 49.89	± 4.70	- .622 ± .031	.387 ± .039
(61)	27	1	X'_{16} =	------	------	------	------	------	------	------	+ .421	- 10.61	± 5.06	+ .538 ± .036	.289 ± .039
(62)	28	1	X'_{16} =	- 1.812	------	------	------	------	------	------	------	+ 34.26	± 5.60	- .357 ± .045	.127 ± .032
(63)	29	1	X'_{16} =	------	------	------	------	- .498	------	------	------	+ 37.05	± 5.71	- .306 ± .046	.093 ± .028
(64)	30	1	X'_{16} =	------	------	------	------	------	------	- .184	------	+ 36.15	± 5.87	- .209 ± .049	.043 ± .020
(65)	31	0	X'_{16} =	------	------	------	------	------	------	------	------	+ 22.89	± 6.00	------------	------------

Equations (35) and (36) differ from each other mainly in the regression coefficient of the length factors and in the constant term, as explained for 22s yarn. The standard errors of these equations are $\pm$ 2.09 and $\pm$ 2.12 pounds which are considerably less than the corresponding ones obtained in connection with 22s yarn, namely, $\pm$ 5.36 and $\pm$ 5.42. However, on a relative basis, the standard errors for the estimated strength of 60s yarn are considerably greater than those found for 22s yarn, the respective figures being 9.2 percent and 5.6 percent based on the respective means.

The coefficient of multiple linear correlation (R) derived from correlating the 6 fiber properties with yarn strength, equation (35), is 0.937 $\pm$ 0.006. This correlation is considered relatively high and compares with a value of 0.935 where the same fiber properties were correlated with strength of 22s yarn. By squaring the coefficient of correlation, a figure of 0.878 is obtained for the coefficient of determination, (R^2). This indicates that 88 percent of the variance in the strength of 60s yarn associated with this series of cottons is accounted for by the 6 fiber properties used in the analysis. This is, in round numbers, 1 percent higher than that found when 22s yarn strength was used.

Referring to equation (36), where the value of upper quartile length was used instead of mean length, R = 0.936 $\pm$ 0.006, and R^2 calculates to be 0.875. Thus, when upper quartile length was used, 88 percent of the yarn-strength variance is explainable by the six fiber properties considered. These results are almost identical with corresponding ones obtained for 22s yarn.

Five fiber properties. Correlation between 8 different combinations of 5 fiber properties and strength of 60s yarn have given results in general line with those obtained with 22s yarn. The equations are based on direct multiple correlation between the variables involved and are listed in table 5 as equations (37), (38), (39), (40), (41), (42), (43), and (44). Comparing the respective standard errors of estimate of equations (37) and (38) with that for equation (36), it appears that, insofar as the effect of grade and percentage of mature fibers on the strength of 60s yarn is concerned, these 2 fiber properties are of little or no importance.

Comparison of the other equations and statistical values may be made in relation to the effect of the separate fiber properties on the strength of 60s yarn, as was done with the 22s yarn. In both cases, the findings are very similar.

Four fiber properties. Correlation between 3 different combinations of 4 fiber properties and strength of 60s yarn have been determined, as shown by equations (45), (46), and (47) in table 5.

In equation (45), where the grade and percentage of mature fibers have been omitted, the standard error of estimate is ± 2.35 as compared with ± 2.12 when all 6 fiber properties are used. Expressed in another way, 85 percent of the yarn-strength variance is accounted for by the 4 fiber properties mentioned in comparison with 88 percent for all 6 fiber properties. Thus, almost as high a precision is obtained with this four-fiber-property equation as is obtained with the six-fiber property equation. Insofar as the estimated strengths of 60s yarn are concerned, therefore, the combined effect of grade and percentage of mature fibers is relatively unimportant; this was found to be the case with 22s yarn also.

Three fiber properties were next studied and the equations developed are listed as (48), (49), and (50) in table 5.

Equation (48) includes the 3 fiber properties of upper quartile length, coefficient of length variability and fiber strength and requires the making of only 2 kinds of laboratory tests. This equation gives estimated strengths of 60s yarn that would be considered almost as good as those when all 6 fiber properties are involved as in equation (36), the respective standard errors being ± 2.77 and ± 2.12. The coefficients of determination for these equations are 0.787 and 0.875, respectively, which indicate that, when only these 3 fiber properties involving 2 kinds of tests are used, 79 percent of the variance in yarn strength is accounted for, as compared with 88 percent when all 6 fiber properties are used. The standard errors of equations (49) and (50), however, are too large for much confidence to be placed upon any estimates so obtained.

Two fiber properties. Six equations have been developed with respect to 2 fiber properties and these are listed in table 5 as (51), (52), (53), (54), (55), and (56).

The only equation involving 2 fiber properties that possesses merit for estimating the strength of 60s yarn is (51), involving mean length and fiber strength. The others have standard errors too high to justify the placing of much reliance upon estimates furnished by them.

Equation (55) is of interest in that the 2 properties involved are grade of cotton and its staple length, both of which may be ascertained in a few minutes by expert cotton classers in contrast with the several hours required for the laboratory measurement of length by the sorter method. The standard error of this equation is ± 4.22, as compared with ± 4.13 for equation (54) where upper quartile length replaces staple length. In the light of the respective R^2 values, 50 percent of the 60s yarn-strength variance is accounted for by grade and staple length, whereas, in the case of grade and upper quartile length, 53 percent is explainable. The results obtained with grade and staple length probably possess somewhat greater significance in application to cotton mixes employed in mill practice than to individual cottons, as explained in connection with the 22s yarn.

SIMPLE CORRELATION BETWEEN SEPARATE FIBER PROPERTIES AND SKEIN STRENGTH OF 22s AND OF 60s YARNS

It is commonly believed by many that some one cotton fiber property is primarily responsible for yarn strength and that yarn strength can be estimated or predicted, for all practical intent and purpose, from a determination of only one fiber property. The separate properties most generally thought of, in this connection, are fiber length, strength, fineness, and grade.

Simple correlation analyses have been made with each of the eight fiber properties and yarn strength, the results of which generally indicate relatively low or poor correlation. The results obtained refer not to the true effect and importance of a particular fiber property in terms of yarn strength but rather to its apparent effect or importance. That is, because of the interrelations that exist between certain fiber properties as previously shown, when the effects of such are disregarded, results are obtained that are inaccurate and that may be misleading as regards the real contribution that a particular fiber property makes to yarn strength and the relative importance that should be attached to it in that respect.

Moreover, to the extent that fiber properties are correlated, when the effect of only one of them at a time is evaluated in relation to yarn strength, a greater or less degree of importance is found for the one under consideration than actually exists for it. For example, cotton fiber length and fineness are correlated to a significant degree (generally speaking, the longer the fiber the finer the fiber) and both fiber length and fineness contribute appreciably to the strength of cotton yarns. However, when fiber fineness is excluded from consideration and only fiber length is used in a simple correlation analysis, the correlation coefficient for the effect of fiber length on yarn strength increases significantly because it involves not the effect of fiber length alone but, also, the effect of fineness to the extent that this fiber property is correlated with fiber length. On the other hand, if fiber length is ignored and only fiber fineness is included in the simple correlation analysis, the correlation coefficient for fiber fineness and yarn strength becomes unduly high. A somewhat similar situation exists with respect to other pairs of fiber properties.

Therefore, since certain of the cotton fiber properties are correlated, it is always problematical as to how much reliance can be placed on the simple correlation coefficients as indicators of the true importance of the respective fiber properties in terms of yarn strength. Such values, however, possess interest from two standpoints: (1) From the standpoint of what is the "apparent" relation between yarn strength and each fiber property when only one at a time is considered and (2) from the standpoint of how much in error conclusions based on simple correlation may be in determining the "true" importance of a separate fiber property to yarn strength, if the effects of other associated fiber properties are not removed.

The statistical findings and equations for the separate fiber properties in relation to the strength of 22s yarn are shown in table 4. They are identified as equations (26), (27), (28), (29), (30), (31), (32), and (33). Equation (34) in this table shows the mean yarn strength of the 384 observations of 22s yarn, followed by its standard error of a single observation.

Corresponding results and equations for the separate fiber properties as related to the strength of 60s yarn are listed in table 5. These are identified as equations (57), (58), (59), (60), (61), (62), (63), and (64). Equation (65) refers to the mean yarn strength of 60s yarn for this series of cottons, together with its standard error of a single observation.

The results from these simple correlation analyses indicate relatively low or poor correlation between the skein strength of these two counts of yarn and any one of the separate fiber properties considered. With both 22s and 60s carded yarn, the highest coefficient of simple correlation was obtained with mean fiber length and the lowest with percentage of mature fibers. The respective figures are + 0.645 and - 0.147 for 22s yarn and + 0.730 and - 0.209 for 60s yarn. Thus, these statistical values are a little higher for 60s yarn than for 22s.

Grade and coefficient of length variability also maintained their same order of rank in the case of both 22s and 60s yarn, namely, the sixth and seventh positions, respectively. However, when the rank based on simple correlation for the other four fiber properties is considered, fiber strength dropped from the second position in the case of 22s yarn to the fifth position with 60s yarn; and upper quartile length, staple length, and fineness each moved up one position in the case of 60s yarn, as compared with their positions with 22s yarn.

The foregoing comparisons are better revealed by the respective ranks of the fiber properties as follows:

Rank	22s	60s
(1)	Mean length	Mean length
(2)	Strength	Upper quartile length
(3)	Upper quartile length	Staple length
(4)	Staple length	Fineness
(5)	Fineness	Strength
(6)	Grade	Grade
(7)	Coef. of length var.	Coef. of length var.
(8)	Percentage of mature fibers	Percentage of mature fibers

The standard errors of estimate for the 8 separate fiber property equations range from $\pm$ 11.53 to $\pm$ 14.92 pounds for 22s yarn and from $\pm$ 4.10 to $\pm$ 5.87 pounds for 60s yarn. Obviously, these standard errors are so large in relation to the mean skein strength for these two counts of yarn that little reliance can be placed upon any estimate of yarn

strength if it is based on a separate fiber property. However, it is of interest to note that the standard errors of estimate associated with several of the separate fiber properties are appreciably less than the standard error of a single observation for the entire series of 384 lots of yarn, namely, $\pm$ 15.08 in the case of the 22s yarn and $\pm$ 6.00 with 60s yarn. These figures indicate if one estimated the yarn strength to be equal to that of the mean strength, that, in two-thirds of the cases, he could expect his estimate of the skein strength of carded yarn made from American Upland cottons of from 5/8 inch to 1-5/16 inch staple length, to be within $\pm$ 15.08 pounds of the actual strength in the case of 22s yarn and within $\pm$ 6.00 pounds of the actual strength in the case of 60s yarn, without the knowledge or consideration of any fiber property.

The standard errors of the single observations are of interest, moreover, in showing how much is gained by estimating the strength for the two counts of yarn when one or more fiber properties are used. For example, if the yarn strength of 60s yarn is arbitrarily estimated to be 22.89 pounds, or the mean strength of the series, the result would be expected to be within $\pm$ 6.00 pounds of the actual figure in two-thirds of the cases whereas if the strength of 60s yarn is estimated from equation (57) involving mean length alone, the estimate would be expected to be within $\pm$ 4.10 pounds of the actual in two-thirds of the cases. The difference in the standard errors, $\pm$ 1.90 pounds per skein, is the maximum benefit derived when the estimate is based on only the one fiber property of mean length. When all six fiber properties are used, however, the standard error is reduced from $\pm$ 6.00 to $\pm$ 2.09, a difference of $\pm$ 3.91 pounds.

As previously pointed out, the rank of importance of the separate fiber properties in terms of yarn strength, as based on simple correlation, is different from that found when partial correlation analysis is applied to the data and is, therefore, misleading to that extent. Although the results obtained with the simple correlations ignore or disregard the effects of other fiber properties, insofar as the latter do not appear in the regression equation, it should be remembered that all pertinent fiber properties exert their effects on the actual yarn strength, even though not measured or not included. Care should be exercised, therefore, when attempting to draw conclusions on the basis of simple correlation coefficients alone. The partial coefficients of correlation constitute the most reliable basis for evaluating the relative contribution or importance of any separate fiber property to yarn strength, or to any other yarn property, and it is these which should be compared if the most reliable conclusions are to be obtained in these respects, as will be presented in the next section.

IMPORTANCE OF EACH FIBER PROPERTY TO YARN SKEIN STRENGTH

The importance of each cotton fiber property with respect to yarn strength, as discussed in the present section, is based on analyses of the data from which the six fiber property equations (2) and (36) were

developed. It is evident from the foregoing correlation studies, however, that a large number of such equations may be derived from the same data, depending upon which and how many fiber properties are taken into consideration.

There are a number of statistical measures that furnish a criterion for the determination of the importance of the various fiber properties, such as, regression coefficients, coefficients of partial correlation, beta coefficients, and coefficients of separate determination. All these have been calculated and considered in these studies but only the values for the first two mentioned measures are included in this presentation. For the most part, the partial correlation coefficients, the beta coefficients, and the coefficients of separate determination are in general agreement and support similar conclusions. By definition and mathematics, however, the partial correlation coefficients are considered more reliable for this purpose than are the beta coefficients and coefficients of separate determination; hence, the values for the latter two statistical measures have been omitted from this presentation.

Regression equations. For ready reference, the regression equations for 22s carded yarn are ranked in table 4, according to the order of decreasing coefficients of correlation and increasing standard errors of estimate. The corresponding ranked regression equations for 60s yarn are shown in table 5. In connection with each equation, the coefficient of determination is listed which, when multiplied by 100, reveals the percentage of yarn-strength variance accounted for by the fiber property or properties under consideration. The difference between the value so obtained and 100 indicates the percentage of yarn-strength variance which is unexplained by the fiber property or properties included in a particular equation.

Regression coefficients. The regression coefficients indicate the amount of change in yarn strength resulting from a unit change in a separate fiber property. Although the magnitudes of the regression coefficients naturally vary with the units of measure employed with each kind of test and, therefore, cannot be used directly for ranking the importance of the various fiber properties with respect to yarn strength, this measure furnishes a practical and understandable yardstick for those unfamiliar with statistical methodology.

The values for the regression coefficients obtained in connection with the six-fiber-property equation (2) for 22s yarn and with the corresponding equation (36) for 60s yarn are listed in table 6, each being followed by its standard error. In every case, the magnitude of the standard error shown is less than one-third of the value for its regression coefficient, which indicates that the magnitude of the latter is significant and not due to chance alone.

Table 6. - Importance of each of 6 measured cotton fiber properties with respect to skein strength of 22s and 60s carded yarns, as indicated by values of regression coefficients obtained from multiple linear correlation analyses of 384 averages of duplicate samples, representing 766 individually tested American Upland cottons, crop years 1935-37

Fiber properties	Regression coefficients for 22s yarn 1/	Regression coefficients for 60s yarn 2/
Grade of cotton, by number	- 1.894 ± 0.32	- 0.783 ± 0.124
Upper quartile length, in inches	+ 31.836 ± 3.77	+ 17.544 ± 1.476
Coefficient of length variability, in percent	- 1.939 ± 0.11	- .688 ± .044
Fiber fineness, micrograms per inch	- 7.318 ± 0.92	- 3.193 ± .359
Percent of mature fibers	- 0.264 ± 0.06	- .146 ± .025
Fiber strength, in 1,000 pounds per square inch	+ 0.942 ± 0.04	+ .276 ± .017

1/ Coefficients of the six fiber property equation (2) for 22s carded yarn.
2/ Coefficients of the six fiber-property equation (36)for 60s carded yarn.

(22s Yarn)

In the light of the data summarized in table 7, the following deductions of practical interest may be made in connection with each measured fiber property towards the strength of carded 22s yarn, assuming that the magnitudes of all the other fiber properties remain the same:

Lowering the grade of cotton by one grade, decreases the skein strength of 22s yarn by 1.89 pounds;

An increase of 1/32 inch in upper quartile length, increases the skein strength of 22s yarn by 0.99 pound;

An increase of 1 percent in the coefficient of length variability, decreases the strength of 22s yarn by 1.94 pounds;

An increase of 1 microgram per inch in fiber weight, decreases the strength of 22s yarn by 7.32 pounds (the coarser the fiber, the lower the yarn strength);

An increase of 1 percent in the percentage of mature fibers, decreases the strength of 22s yarn by 0.26 pound;

And, an increase of 1,000 pounds per square inch in fiber strength, increases the strength of 22s yarn by 0.94 pound.

The results, expressed another way (see table 7), show that an increase of 1 pound in the skein strength of 22s carded yarn is obtained by --

Raising the grade of cotton by 0.53 step; or

Increasing the upper quartile length by 1/32 inch; or

Decreasing the coefficient of length variability by 0.52 percent; or

Decreasing the fiber weight per inch by 0.14 microgram (the finer the fiber, the stronger the yarn); or

Decreasing the percentage of mature fibers by 3.79 percent; or

Increasing fiber strength by 1,060 pounds per square inch.

Data also are shown in table 7 relative to the amount of change in each fiber property required to produce a 1 percent increase in the mean strength of 22s yarn. However, since the mean yarn strength of the series is 95.84 pounds, such necessary changes in the respective fiber properties are practically the same as those required to cause a 1-pound increase of yarn strength.

Table 7. - Effect of change in each of 6 measured cotton fiber properties on skein strength of 22s and 60s carded yarns, as based on regression coefficients obtained from multiple linear correlation analyses of 384 averages of duplicate samples, representing 766 individually tested American Upland cottons, crop years 1935-37

Change in skein strength of				Change in fiber property of					
22s yarn 1/		60s yarn 2/		Grade of cotton	Upper quartile length	Coef. of length var.	Fineness, fiber wt. per inch	Mature fibers	Fiber strength
Pounds	Percent 3/	Pounds	Percent 4/	Number 5/	Inches	Percent	Micrograms 6/	Percent	1,000 pounds per sq. in.
- 1.89	- 1.97	- 0.78	- 3.41	+ 1					
+ 0.99	+ 1.03	+ 0.55	+ 2.40		+ 1/32				
- 1.94	- 2.02	- 0.69	- 3.01			+ 1			
- 7.32	- 7.64	- 3.19	- 13.94				+ 1		
- 0.26	- 0.27	- 0.15	- 0.66					+ 1	
+ 0.94	+ 0.98	+ 0.28	+ 1.22						+ 1
+ 1.00	+ 1.04	------	------	- 0.53	+ 1/32	- 0.52	- 0.14	- 3.79	+ 1.060
------	------	+ 1.00	+ 4.37	- 1.28	+ 1/16	- 1.45	- 0.31	- 6.85	+ 3.623
+ 0.96	+ 1.00	------	------	- 0.51	+ 1/32	- 0.49	- 0.13	- 3.63	+ 1.017
------	------	+ 0.23	+ 1.00	- 0.29	+ 1/64	- 0.33	- 0.07	- 1.57	+ 0.830

1/ Based on the regression coefficients of the six fiber-property equation (2) for 22s carded yarn.
2/ Based on the regression coefficients of the six fiber-property equation (36) for 60s carded yarn.
3/ As based on 95.84 pounds, the mean strength of 22s carded yarn.
4/ As based on 22.89 pounds, the mean strength of 60s carded yarn.
5/ An increase of 1 grade number is equivalent to lowering the grade of the cotton by one step, such as from Strict Middling (grade 4) to Middling (grade 5).
6/ An increase of 1 microgram per inch indicates that the fiber is less fine, or is coarser.

(60s Yarn)

On the basis of the data summarized in table 7, the following deductions of practical interest may be made in connection with each measured fiber property towards the strength of carded 60s yarn, assuming that the magnitudes of all the other fiber properties remain the same:

Lowering the grade of cotton by one grade, decreases the skein strength of 60s yarn by 0.78 pound;

An increase in upper quartile length of 1/32 inch, increases the skein strength of 60s yarn by 0.55 pound;

An increase of 1 percent in the coefficient of length variability, decreases 60s yarn strength by 0.69 pound;

An increase of 1 microgram per inch in fiber weight, decreases 60s yarn strength by 3.19 pounds (the coarser the fiber, the lower the yarn strength);

An increase of 1 percent in the percentage of mature fibers, decreases 60s yarn strength by 0.15 pound;

And, an increase of 1,000 pounds per square inch in fiber strength increases 60s yarn strength by 0.28 pound.

Expressed in another manner, the values listed in table 7 show that an increase of 1 pound in the skein strength of 60s yarn is obtained by --

Raising the grade of cotton by 1.28 steps; or

Increasing the upper quartile length by 1/16 inch; or

Decreasing the coefficient of length variability by 1.45 percent; or

Decreasing the fiber weight per inch by 0.31 microgram (the finer the fiber, the stronger the yarn); or

Decreasing the percentage of mature fibers by 6.85 percent; or

Increasing fiber strength by 3,623 pounds per square inch.

Figures also are given in table 7 for the amount of change in each fiber property necessary to cause an increase of 1 percent in the mean strength of 60s yarn. In this connection, it is of interest to note that the amount of change in the respective fiber properties necessary to cause an increase of 1 pound in yarn strength is from 2 to 3.4 times greater for 60s yarn than for 22s yarn. However, the amount of change in the different fiber properties required to produce a 1 percent increase in mean yarn strength is from 1.2 to 2.3 times greater for 22s yarn than for 60s yarn.

Partial correlation coefficients. Referring to table 8, the values for this statistical measure indicate that the properties of raw cotton studied in this instance rank in order of importance to the skein strength of 22s and 60s carded yarn, as follows: Fiber strength, coefficient of length variability, upper quartile length, fiber fineness, grade, and percentage of mature fibers.

Although the rank of importance of the different fiber properties, as based on partial correlation coefficients, is the same for both 22s and 60s yarn, it should be noted that the magnitudes of the respective coefficients differ somewhat with the two yarn counts. In particular, there is evidence that fiber length is more important to the strength of 60s yarn than to the strength of 22s yarn; and that fiber strength is more important to the strength of 22s yarn than to the strength of 60s yarn. These differences appear logical since, in the finer counts of yarn, no matter how strong the fibers may be, such fiber strength cannot be realized unless the relatively few fibers in the yarn cross-section possess sufficient length for the inserted yarn twist to bind them properly. Moreover, other factors being equal, length of fiber determines the highest count into which a cotton may be spun as observed in actual mill practice.

What the exact rank of importance would be for the 6 cotton fiber properties in reference to the strength of much finer counts of carded and combed yarn is somewhat problematical. In the case of combed yarns of 120s and 200s, for example, it is possible that fiber length would assume more importance to yarn strength and fiber strength less importance, as compared with their respective contributions to the strength of carded yarn listed herein. Differences in the effects of fiber length and fiber strength might even become great enough in such extremely fine yarns as to reverse the rank of importance obtained for them in connection with the strength of 22s and 60s carded yarn.

Therefore, in connection with the statistical values and conclusions presented in this paper with respect to the importance of the fiber properties under study, it should be remembered that they pertain only to the skein strength of carded yarns manufactured from American Upland cottons and, then, only to such yarns of 22s and 60s counts. Studies of the same fiber data correlated with yarn appearance, with tire-cord strength, with tire-cord elongation, and with percentage of picker and card waste reveal a somewhat different picture for the over-all correlation and for the relative importance of the different fiber properties. More particularly, in certain of these other instances, some of the fiber properties that are relatively important to the strength of carded yarn have been found to be comparatively unimportant, and vice versa.

APPLICATION OF REGRESSION EQUATIONS

Over 70 regression equations have been developed in connection with this study for estimating the skein strength of carded yarn, 31 of which are presented in table 4 for 22s yarn; 31 in table 5 for 60s yarn; and 4

Table 8. - Rank of importance of 6 measured cotton fiber properties with respect to skein strength of 22s and 60s carded yarns, as indicated by values of partial correlation coefficients obtained from multiple linear correlation analyses of 384 averages of duplicate samples, representing 766 individually tested American Upland cottons, crop years 1935-37

Rank	Fiber properties	Partial correlation coefficients for	
		22s yarn	60s yarn
1	Fiber strength, in 1,000 pounds per sq. in.	+ 0.750 ± 0.022	+ 0.648 ± 0.030
2	Coef. of length variability, in percent	- 0.658 ± .029	- 0.622 ± .031
3	Upper quartile length, in inches	+ 0.395 ± .043	+ 0.519 ± .037
4	Fiber fineness, micrograms per inch	- 0.377 ± .044	- 0.414 ± .042
5	Grade of cotton, by number	- 0.291 ± .047	- 0.307 ± .046
6	Percent of mature fibers	- 0.209 ± .049	- 0.289 ± .047

in the Discussion having to do with special cases. (see pp. 42, 44.) The remaining equations have not been included in this report but the statistical findings associated with them have served as a basis for certain statements made in the next section.

For practical use and operation of the equations presented herein, reference may be made to the example illustrated in the Appendix.

Although the skein strengths of only 22s and 60s yarn may be predicted directly from the equations reported, practically anyestimated yarn strength may be obtained for counts within this range and for those outside of the range, particularly in the lower counts, by applying the conversion formula given in publication 10/ and whose use is explained in the Appendix with more particular reference to the estimating equations. By means of this formula, a very much wider and more general application of the equations and findings reported in this paper can be made than otherwise would be possible. This is a practical solution to an unwieldy problem. Obviously, to have developed estimating equations for every count of carded yarn, or even for the most common counts of such yarns, would have required a prohibitive amount of technical and clerical work.

That a number of more or less radically different yarn-strength estimating equations with various degrees of reliability can be obtained from analysing the data for a given series of cottons, depending upon which and how many fiber properties are correlated, is fully demonstrated by the evidence presented in tables 4 and 5 and in the graphic charts which follow. It is felt, however, that the equations presented in this paper possess merit for making comparisons and predictions in reference to yarn skein strength and cotton quality, insofar as American Upland cottons are concerned, since they were derived from analysing such a large number of cottons; since such wide ranges of fiber and spinning properties were involved, and since such comparable methods and conditions of test were used with all samples.

Estimated values of yarn strength obtained for other American Upland cottons by substituting fiber-property values in any of these equations generally should agree with their actual yarn-strength values, within the limits of tolerance specified, provided that a number of conditions are satisfactorily met. There will be individual cases, however, where the estimated and actual values of yarn strength will differ more than the limits of accuracy indicated. In such event, it is likely that either the equation is being applied to an unusual or extreme cotton, one that is distinctly outside of the range, in one or more fiber properties, of that from which these equations were developed, or else that the techniques and conditions used by others for measuring fiber and yarn properties or for manufacturing yarn are appreciably different from those employed in these analyses, or both. If only an occasional large disparity occurs and if the deviations are sometimes plus and sometimes minus, this

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10/ See footnote 8/, page 10.

would suggest something unusual or extreme about the cotton. On the other hand, if appreciable disparities occur generally and if they are always either plus or minus, this would indicate that something is unusual or peculiar to the testing or manufacturing phases.

The following are examples within the second category of disparities mentioned above:

If large numbers of fibers are broken during the length-sorting process whereby the upper quartile length becomes unduly short and the coefficient of length variability becomes unduly high, estimated yarn strengths based on such values will be low in comparison with the yarn strengths actually obtained.

If the fiber strength tests are not properly performed and the resulting values are low for some reason, the estimated yarn strength would be expected to be low.

If the yarns are manufactured on a long-draft system, estimated yarn strengths should be some 5 to 15 percent lower than the actual values obtained, as the equations presented in this paper are based on yarn strengths obtained with the so-called regular draft.

If the yarn twist employed in the manufacture of a cotton is below or above the optimum for its staple length, estimated yarn strength values for it based on these equations would be expected to be relatively high, since the equations here reported represent yarn strengths associated with yarn twists giving maximum yarn strength.

If the yarn-skein strength tests are improperly made, the estimated yarn strengths by comparison may be either high or low.

If the fiber and yarn tests are made under atmospheric conditions above or below a temperature of 70° F. and a relative humidity of 65 percent, estimated yarn strength values may be either high or low, as the values on which these equations are based were obtained under standard atmospheric conditions.

DISCUSSION

The large number of equations presented have been derived in an effort to determine: How closely yarn strength can be predicted from only a knowledge of certain fiber properties? How much of the yarn strength variance is explainable by eight separate and variously combined fiber properties? Which combination of fiber properties gives the best results? Which and how many tests may be omitted and yet give sufficient data for estimating or predicting yarn-skein strength with practical satisfaction, the degree of which may vary for different purposes? And how closely an estimated yarn strength may be obtained when based alone on such non-technical measurements as grade and staple length?

From the data presented, it is evident that yarn strength is not the result of the influence of just 1 fiber property, nor of any 2 or 3 fiber properties, but rather of many contributing variables. It also is obvious that many interrelationships and interactions are involved in this problem and that, as comprehensive as this study is, not all of them have been included. The cumulative and compensative effects of fiber properties not measured frequently are overlooked or forgotten when making interpretations with respect to the measured fiber properties included in such statistical analyses; nevertheless, they always contribute to some extent in increasing or decreasing the actual yarn strength values involved and, thereby, influence the findings and conclusions from any such statistical analyses.

Using the six-fiber-property equations which reflect the highest coefficient of correlation and the lowest standard error of estimate, 87 percent of the yarn strength variance is explained by the measurements for the fiber properties considered in the case of equation (2) for 22s yarn and 88 percent in the case of equation (36) for 60s yarn. Thus, 13 percent and 12 percent of the variance in yarn strength of the 2 respective counts are unaccounted for by the 6 fiber properties included and these disparities are believed to result from other fiber properties and factors beyond control. A lesser proportion of the yarn-strength variance is accounted for and a corresponding greater amount is unexplained, of course, as different combinations of fewer fiber properties are used. Generally, the least amount of yarn-strength variance is accounted for by the separate fiber properties, though the different fiber properties vary considerably in this respect.

Evidence obtained from these and related studies made over a period of years has shown that the nature and extent of the distribution of the various fiber properties are of particular importance when data are analysed to obtain regression or estimating equations with respect to cotton quality. Such equations have generally agreed when the ranges and distribution of the fiber properties were comparable. When one or more of the fiber properties of the various series of cottons had relatively narrow ranges, however, the equations were radically different, particularly with respect to the regression coefficients of those variables having a narrow range. Variation in the concentration of the magnitudes of the fiber properties tend to weight the data for these fiber properties in such diverse ways that precise or perfect agreement between such statistical measures derived from different groups of cotton can hardly be expected. The full effect of the extreme fiber properties, moreover, is often obscured by such weighting.

To illustrate, a multiple correlation coefficient of 0.873 was found for a series of 113 lots of cotton in which five fiber properties were correlated with the strength of 22s carded yarn. However, when 40 of the cottons were selected from this series so that the magnitudes of the fiber properties were more equally distributed over their respective ranges and the proportion of fiber properties near the extremes

was considerably increased, the multiple correlation coefficient became 0.937. This is a sizeable improvement. Although 3 or 4 times more weight was given to the extreme fiber properties in this instance than before, the frequency of the magnitudes of the fiber properties near the means still possessed more weight in the calculations than those near the extremes.

A further study of the effect of this factor has been followed by a somewhat similar procedure in connection with the present studies. Twenty-five cottons were selected primarily on the basis of their 22s yarn strength. They differed by about 4 pounds - starting at the minimum of 49 pounds and ending with the maximum of 142 pounds - and covered approximately the full range of each of the fiber properties. When 6 fiber properties were correlated with the strength of yarn, a multiple correlation coefficient of 0.969 was found for these cottons, as compared with 0.933 for the 384 lots of cotton. This is a substantial improvement and a very high correlation for cotton fiber-and-yarn relationships, particularly since 1.000 represents perfect correlation, since all contributing fiber properties were not included, and since some errors accompany even the best of sampling and testing methods. The results are of more particular interest in this instance, however, in that they indicate the extent to which correlation coefficients pertaining to cotton quality can be affected or masked by inadvertent weighting of the measurements for fiber and spinning properties, as a result of the distribution of the samples and data included in the analysis.

The corresponding coefficients of determination associated with the two series of cottons cited above are 0.939 and 0.871, respectively. These figures indicate that 94 percent of the variance in strength of 22s yarn is accounted for by the 6 fiber properties in the case of the 25 selected cottons and 87 percent in the case of the entire series of 384 lots of cotton. The former finding is significant in that it offers proof of the following conclusions: (1) That the fiber properties included in the studies constitute the principal ones involved in yarn strength and (2) that the relationship between yarn strength and these fiber properties can be explained by linear correlation without recourse to the tedious process of curvilinear correlation analyses.

The latter conclusion has been confirmed by applying curvilinear analysis to the data, using one of the methods described by Thomsen 11/. The studies were made on the 25 selected cottons previously mentioned when yarn strength ranged from 49 pounds to 142 pounds. The various charts constructed in connection with this analysis failed to reveal any definite trend towards curvilinear relationships.

In view of the fact that so many different equations may be obtained for a given series of cottons, it should be emphasized that the

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11/ Agricultural Prices, by Frederick Lundy Thomsen. McGraw-Hill Book Co., Inc., New York, 1936.

measured importance reported for each of the separate fiber properties, with respect to yarn strength, as based on partial correlation coefficients, is related to the six fiber properties involved in equation (2) in the case of 22s yarn and to the same six fiber properties of the corresponding equation (36) for 60s yarn. The reported importance for each separate fiber property is subject to the restriction that it holds precisely only for the number and nature of the fiber properties used in the analysis, for the methods of test applied, and for the units of measurement employed in the calculations of the fiber and yarn properties. Such restrictions and reservations, nevertheless, always apply to any correlation analyses and findings of this type.

In pursuing this line of reasoning further, an analysis has been made to determine the extent to which the averaging of data for corresponding samples from plots 1 and 8 affected the interpretations and conclusions obtained in this study. The method used was to calculate the residuals by estimating the strength of 22s yarn for cottons of each plot, 1 and 8 separately, using equation (2), and adjusting the constant term so that the residuals would add to 0. The equation obtained, therefore, differs from equation (2) only in the value of the constant term, the difference being 0.71 pound. The standard error for the equation is $\pm$ 6.22 pounds, when the data for plots 1 and 8 are considered individually, as compared with $\pm$ 5.42 pounds when the data for plots 1 and 8 are averaged. The higher standard error naturally follows for the series based on single observations, in comparison with the smaller one derived from using averages of the data from duplicate plots.

In the light of the foregoing, care must be used in basing conclusions on any correlation analyses where averages are used indiscriminately, since averaging reduces the scatter and since, other factors being equal, a reduced scatter increases the coefficient of correlation and decreases the standard error. The correlation coefficients reported in this paper on the basis of averages for the 384 duplicate cottons, therefore, are slightly higher than would have been the case had all 766 observations been used individually. The regression equations, however, would have been essentially the same. Moreover, as all the data have been calculated throughout on the basis of averages for duplicate plots, the equations and other statistical measures presented are comparable. Thus, averaging in this instance has done no violence to the practical interpretations and conclusions reported in this paper.

An important feature of the regression equations presented is the degree of precision that they possess with respect to estimates of yarn strength. The precisions of the respective equations, as based on absolute units, are indicated by the standard errors listed in tables 4 and 5. It will be noted that the standard errors for the 60s yarn are much smaller than those for the 22s yarn. The standard errors of the 60s, however, are not directly comparable with those found in the case of 22s yarn, since the average strength for the 60s yarn is 22.89 pounds while that for the 22s yarn is 95.84 pounds.

Based on percentage deviations, as obtained by dividing the difference between the actual and estimated values by the actual values, the precision of the equations for estimating the strength of 60s yarn is generally less than that for 22s yarn. This conclusion is based on the following figures: With 60s yarn, the best equation from the standpoint of percentage precision is equation (36), giving 73 percent of the estimated yarn strengths occurring within $\pm$ 10 percent of the actual strengths. This compares with the corresponding value of 94 percent for equation (2) with 22s yarn. The other respective equations for 60s and 22s yarn indicate about the same proportion of difference between results.

The foregoing discussion is based on identical cottons used in estimating the strength of both 22s and 60s yarn, the estimated strengths of 22s yarn being compared with actual strengths of 22s yarn in all 384 cases; whereas the estimated strength of 60s yarn was compared with actual strengths of 60s yarn in 102 cases and with converted actual strengths in 282 instances. The 102 cottons were spun into 60s as the finest count rather than 36s, 44s, or 50s because their staple lengths were 1-1/32 inches or longer whereas the other cottons of the series were shorter than 1-1/32 inches. The question now arises as to what the equation would have been had only actual strengths of the 102 lots of 60s yarn been used, instead of actual and converted figures for 384 lots, and how closely can 60s yarn strength be estimated by such an equation.

When the correlation results are based on the 102 lots of cotton actually spun into 60s yarn, a coefficient of multiple correlation of 0.943 is obtained which, on squaring, indicates that 89 percent of the variance in strength of 60s yarn is accounted for by the 6 fiber properties under consideration. This compares with 88 percent when the entire 384 cottons of the series were used. The standard error of the equation for the 102 cottons is $\pm$ 1.85 as compared with $\pm$ 2.12 for the 384 lots. This lower standard error is largely the result of the narrower range of the actual strength of 60s yarn associated with the 102 lots, as compared with the wider range when 384 lots were used. The fact that only 1 percent less of the variance in 60s yarn strength is accounted for when 384 lots were used, as compared with the 102 lots, indicates that no violence was done to the raw data by conversion.

For convenience in comparing the findings obtained with the two series of cottons referred to above, the two equations are given below, equation (36) referring to the 384 lots and equation (66) to the 102 lots:

$$(36)\ X'_{16} = 31.97 - .783X_1 + 17.544X_2 - .688X_3 - 3.193X_4 - .146X_{35} + .276X_6$$

$$(66)\ X'_{16} = 37.80 - .198X_1 + 18.880X_2 - .876X_3 - 2.973X_4 - .238X_{35} + .280X_6$$

In comparing the above equations, it is seen that the regression coefficients differ mostly for grade and to a sizeable extent for length variability and percentage of mature fibers. The differences are explainable, to a certain degree, by the fact that the two series of cottons

differed in their range and distribution of fiber properties. In particular, in the case of the 102 lots, the cottons possessed a more restricted range of grades and, in addition, a higher concentration of grades within a narrow range than did those of the 384 lots, 97.0 percent of the cottons having grades within the range of Middling to Low Middling for the former and 85.9 percent for the latter. Thus, grade had little chance to affect the results in this instance and this is borne out by the fact that the regression coefficient for grade is so much smaller in equation (66) than it is in equation (36).

A check also has been made of the reliability of the formula 12/ that has been used in converting the strengths of lower counts into those of 60s yarn and that is recommended for use with the equations when estimating the strength of carded yarns for counts other than 22s and 60s. First, since cottons from plots 1 and 8 differed only in their growth location within the same field, little difference should be expected in the strength of 60s yarns from the two corresponding plots. This has, in fact, been confirmed by averaging the strengths of the 60s yarn actually spun from 102 cottons grown on plots 1 and comparing the result with that found for the corresponding cottons grown on plot 8. The respective averages are 28.35 and 28.26 pounds. This is a difference of only 0.09 pound and, obviously, is much too small to be significant. Thus, the reliability of the basis for the comparisons to follow is established.

Next, in the conversion from the strength of 50s yarn to that of 60s yarn, there were 33 cases where cotton from plots 1 and 8 were spun into either 50s or 60s yarn. The average yarn strength for the 33 cottons actually spun into 60s yarn is 23.91 pounds, as compared with 23.42 pounds for the average of the 33 cottons converted by formula from 50s to 60s yarn strength. This is a difference of only 0.49 pound and indicates that no violence was done to the data by such conversions. With respect to 44s yarn, there were 102 lots from which both 44s and 60s yarn were spun. The average strength of the 60s converted from 44s was 26.7 pounds, as compared with 28.2 pounds for the actual 60s yarn strength, or a difference of 1.5 pounds.

By way of further breakdown, the 384 average yarn-strength values used in this paper for 60s yarn can be classified as follows: 102 cases represent actual 60s yarn spun and tested; 33 cases, conversion from 50s to 60s in only one of the duplicate plots; 132 cases, conversion from 50s to 60s in both plots; and 73 cases, conversion from 44s to 60s in both plots. Thus, a total of 340 strength averages out of 384 are considered practically as reliable as if 60s yarn had been spun and tested. No direct check, however, is possible on the strengths of the remaining 44 lots of yarn, aggregating 11.4 percent of the total cases.

12/ See footnote 8/, page 10.

In the light of the foregoing, it seems safe to conclude that the slight disagreement between the precision of equation (36) for the 384 lots and that of equation (66) for the 102 lots is the result of differences in the range and distribution of the fiber properties and also of the yarn-strength values, rather than of any differences caused by converting the strengths of lower counts into those of 60s yarns. Even so, it is regretted that any converted values had to be used in connection with the 384 lots of 60s yarn. However, to have compared the results of 60s yarn with 22s yarn on the basis of only the data pertaining to the cottons actually spun in the two cases would have, in effect, been the equivalent of comparing the results from two different series of cotons having considerably different ranges and distributions of fiber properties, particularly with respect to length. Such a procedure, therefore, would have imposed serious restrictions on any attempted over-all interpretations and conclusions.

Previous mention has been made in this report of three equations concerning 22s yarn which did not appear in table 4. Those equations refer to upper quartile length multiplied by fiber strength divided by fiber weight fineness, the product of mean fiber length and fiber strength, and the product of upper quartile length and fiber strength, and are respectively as follows:

		S
(16)	$X_8' = 58.05 + \dfrac{1.990 X_2 X_6}{X_4}$	$\pm$ 10.18
(19)	$X_8' = 13.81 + 1.136 X_{11} X_6$	$\pm$ 7.52
(20)	$X_8' = 16.25 \quad .921 X_2 X_6$	$\pm$ 8.49

A comparison of the standard errors of these equations with those of table 4, in which the same fiber properties were used in regular linear correlation analyses, shows that nothing is gained by the use of the product method.

Scatter diagrams of the type explained in the Appendix, when arranged in serial order, are particularly helpful in affording a proper understanding of the precision of fiber-yarn relationships, as established by regression equations.

For assistance in visualizing the results obtained in this study, figures 1 to 12, comparing the actual with the estimated strength of 22s yarn, are presented. No graphic illustrations, however, are shown for 60s yarn, as the general results for both counts of yarn are very similar.

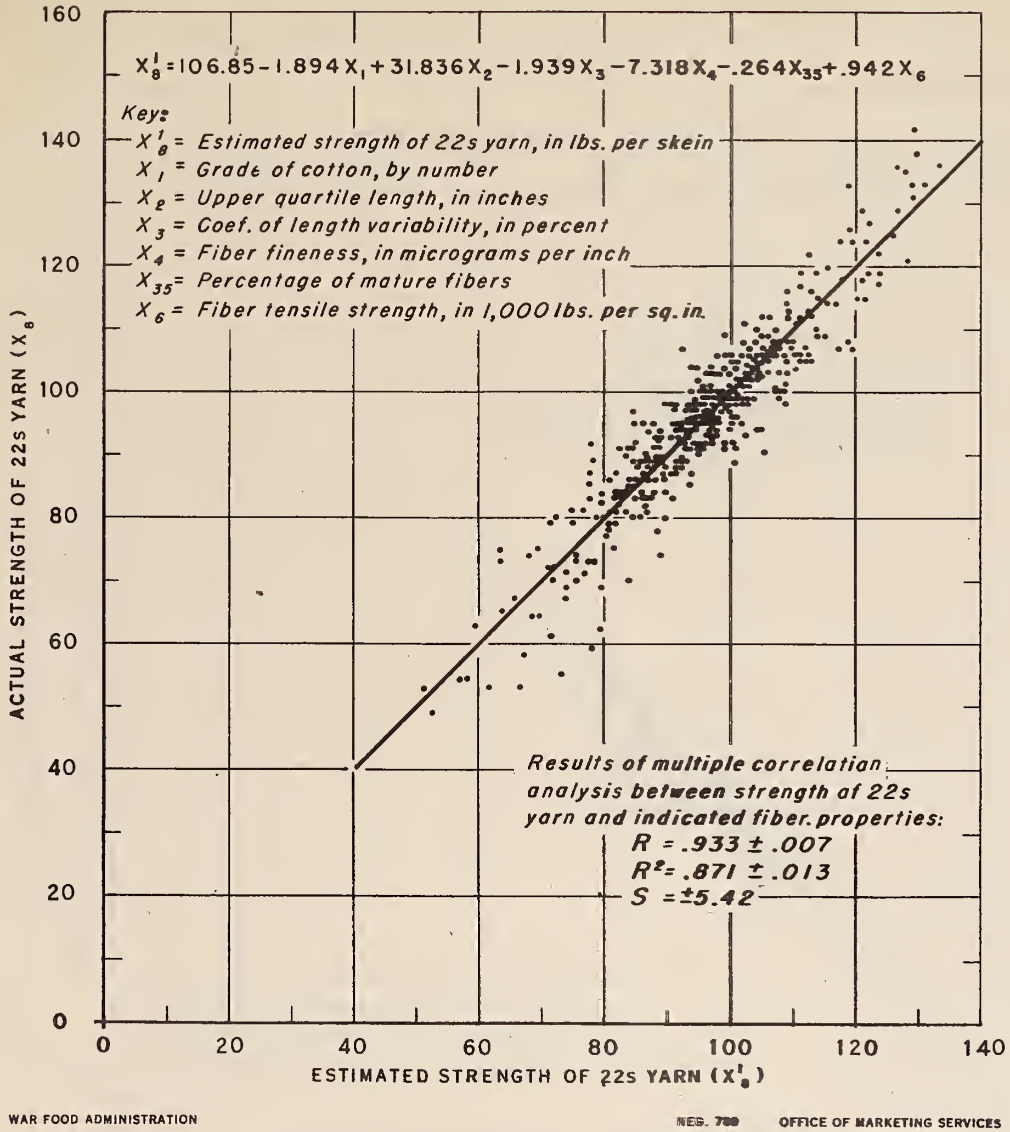

FIGURE 1—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Multiple Regression Equation (2)

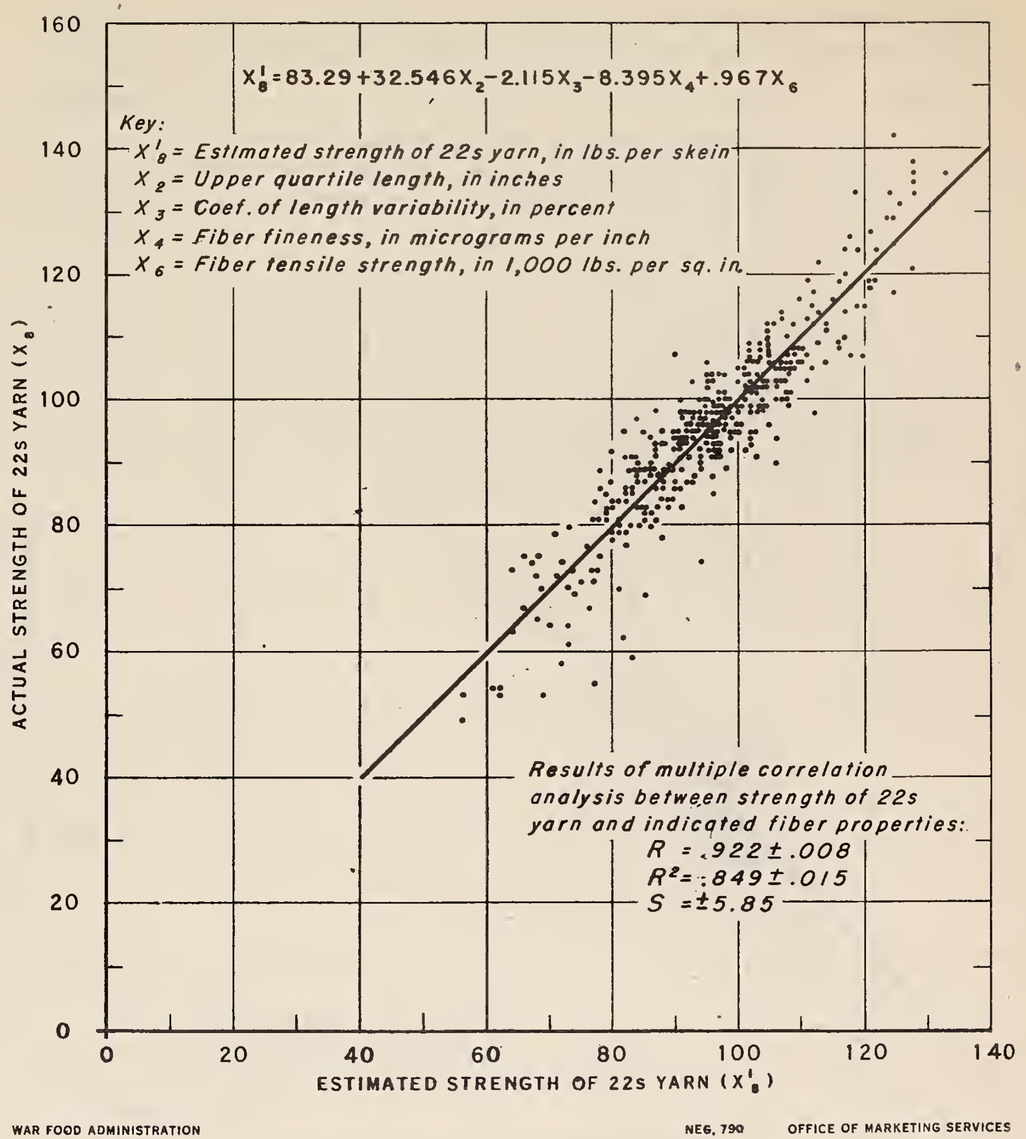

FIGURE 2—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Multiple Regression Equation (11)

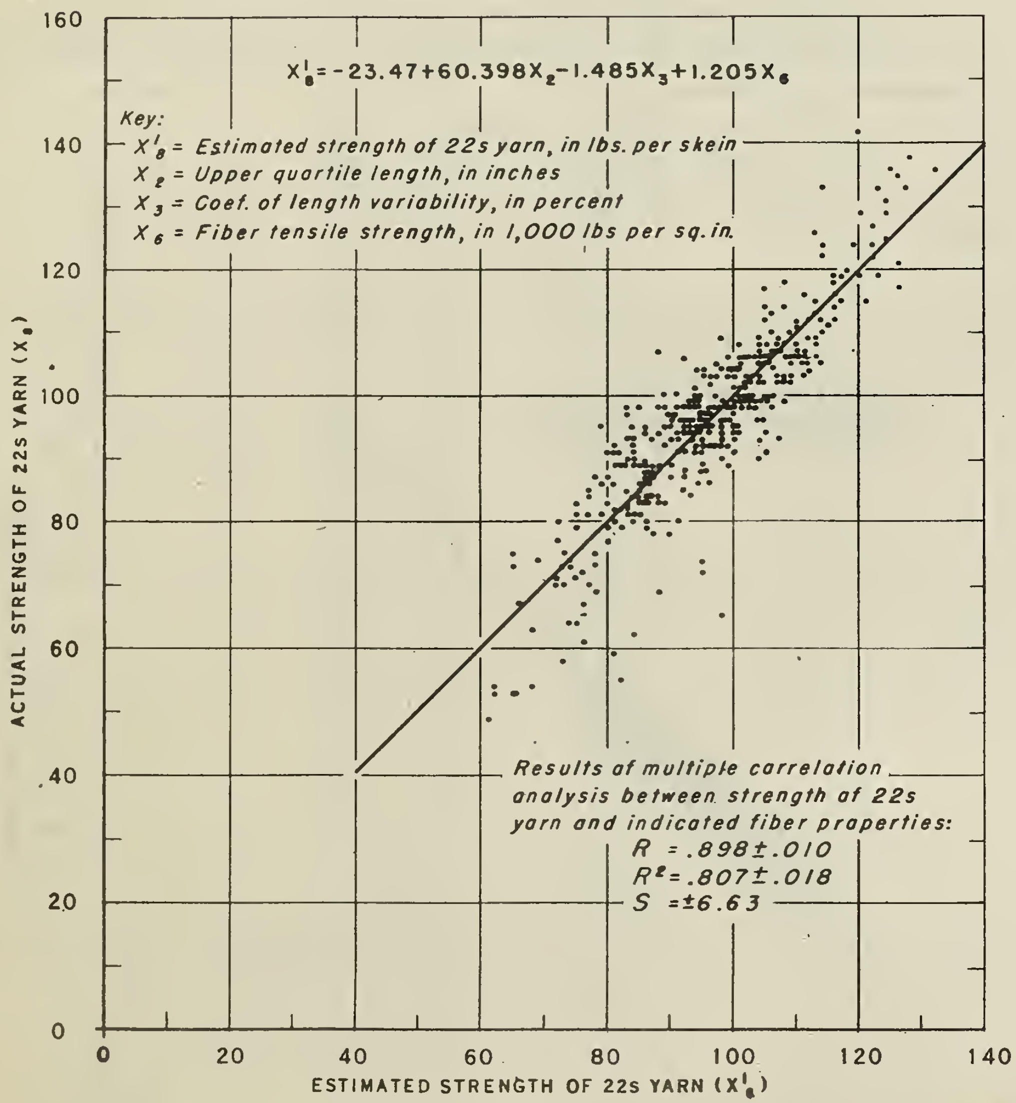

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FIGURE 3—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Multiple Regression Equation (14)

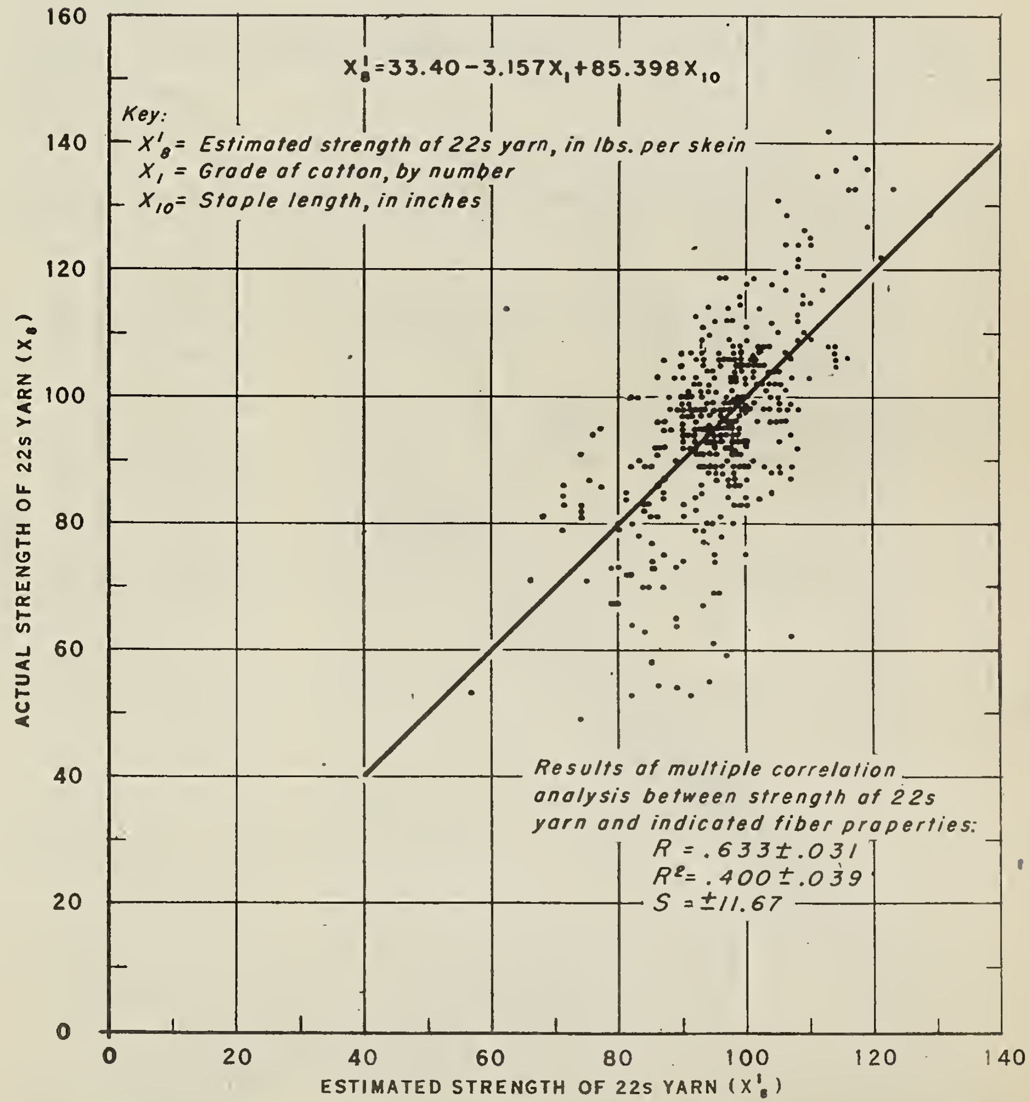

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FIGURE 4—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Multiple Regression Equation (25)

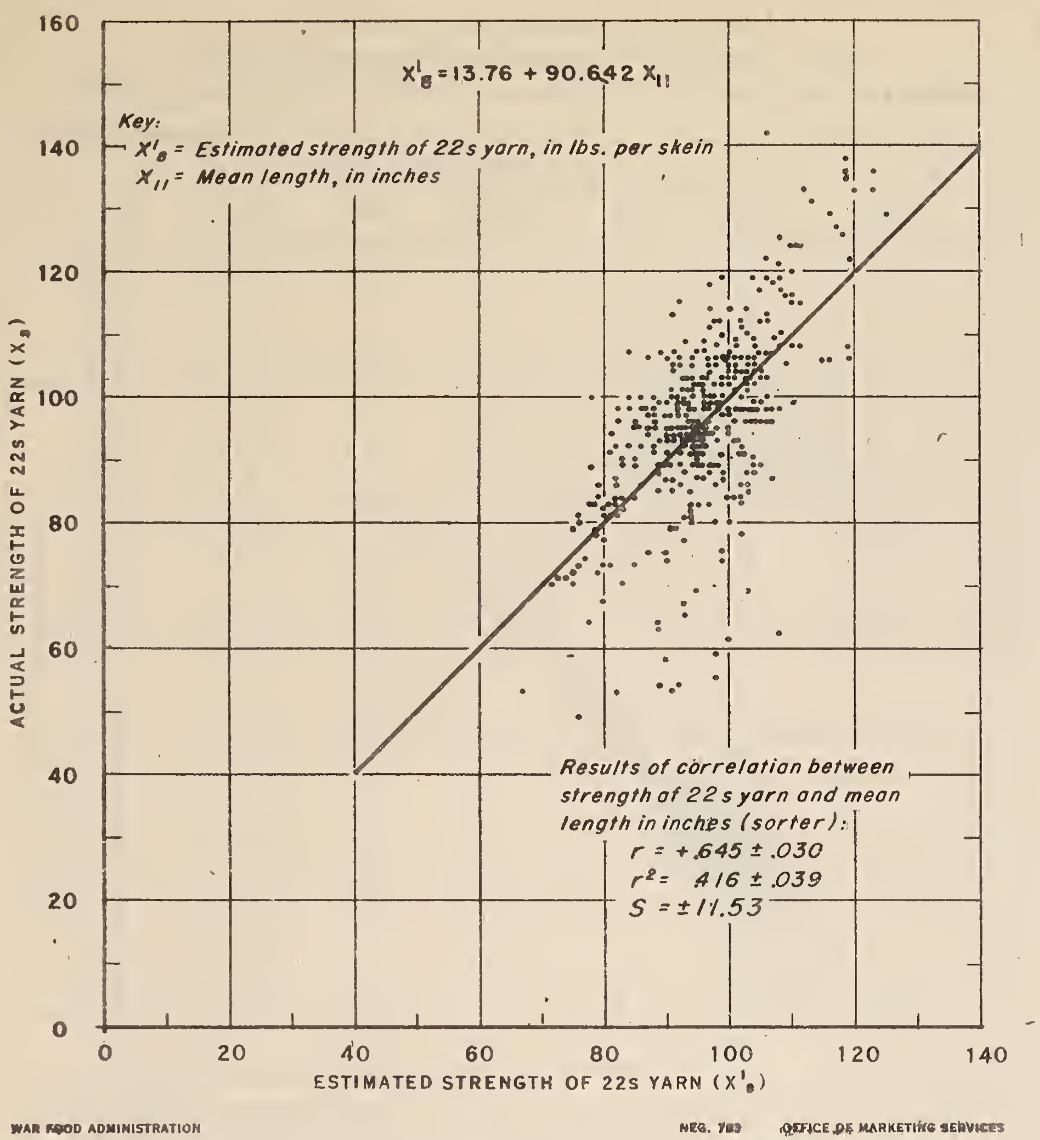

FIGURE 5—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (26) Derived From Simple Correlation

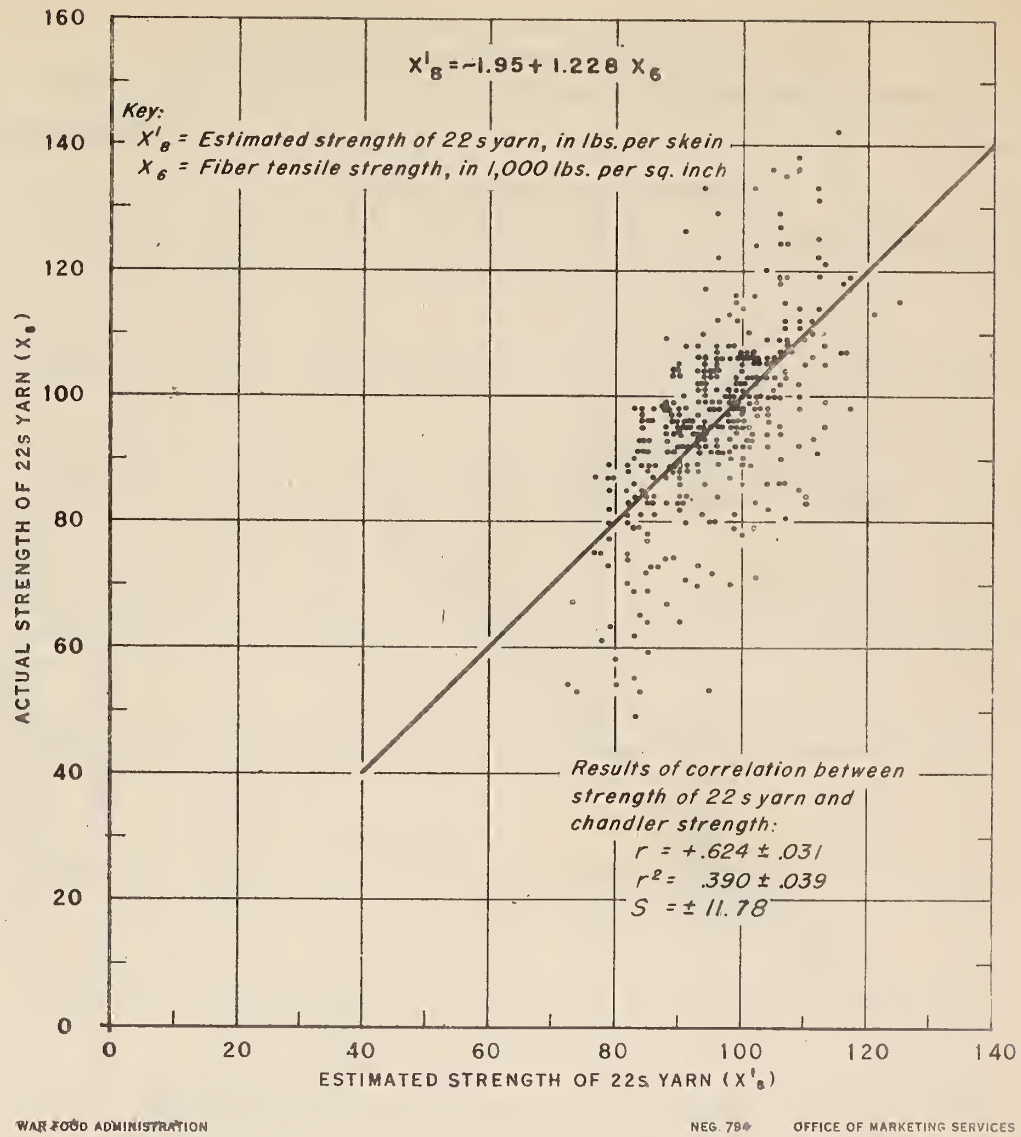

FIGURE 6—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (27) Derived From Simple Correlation

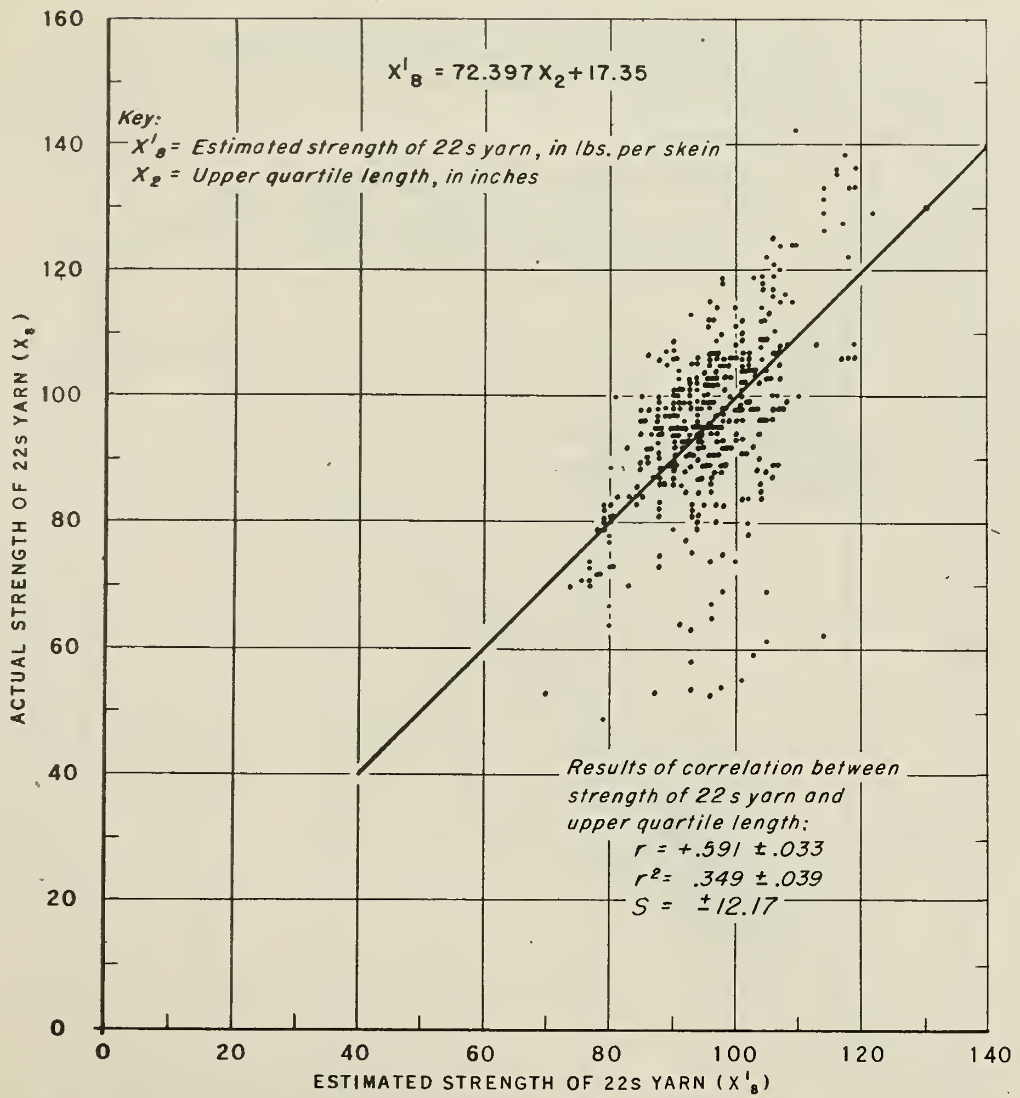

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FIGURE 7—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (28) Derived From Simple Correlation

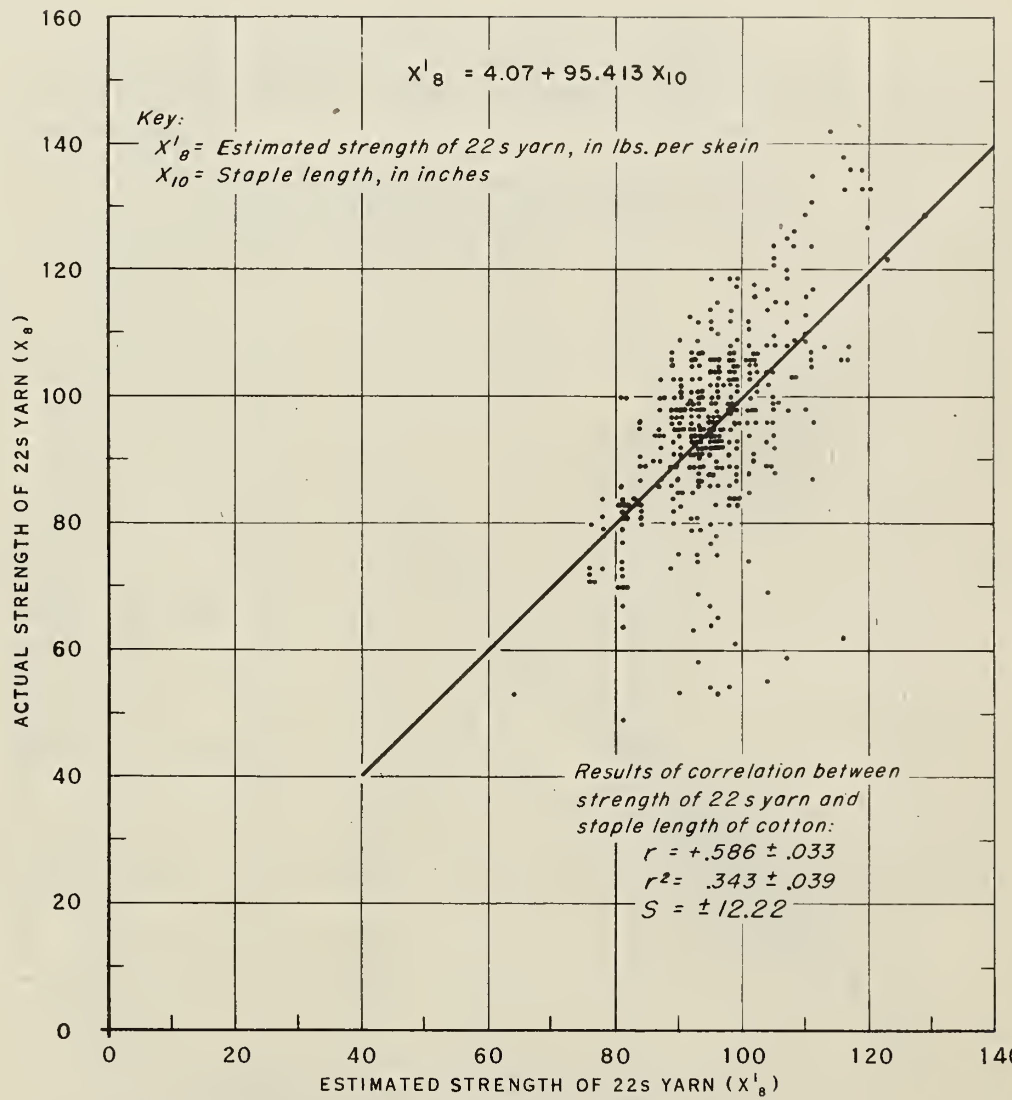

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FIGURE 8—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (29) Derived From Simple Correlation

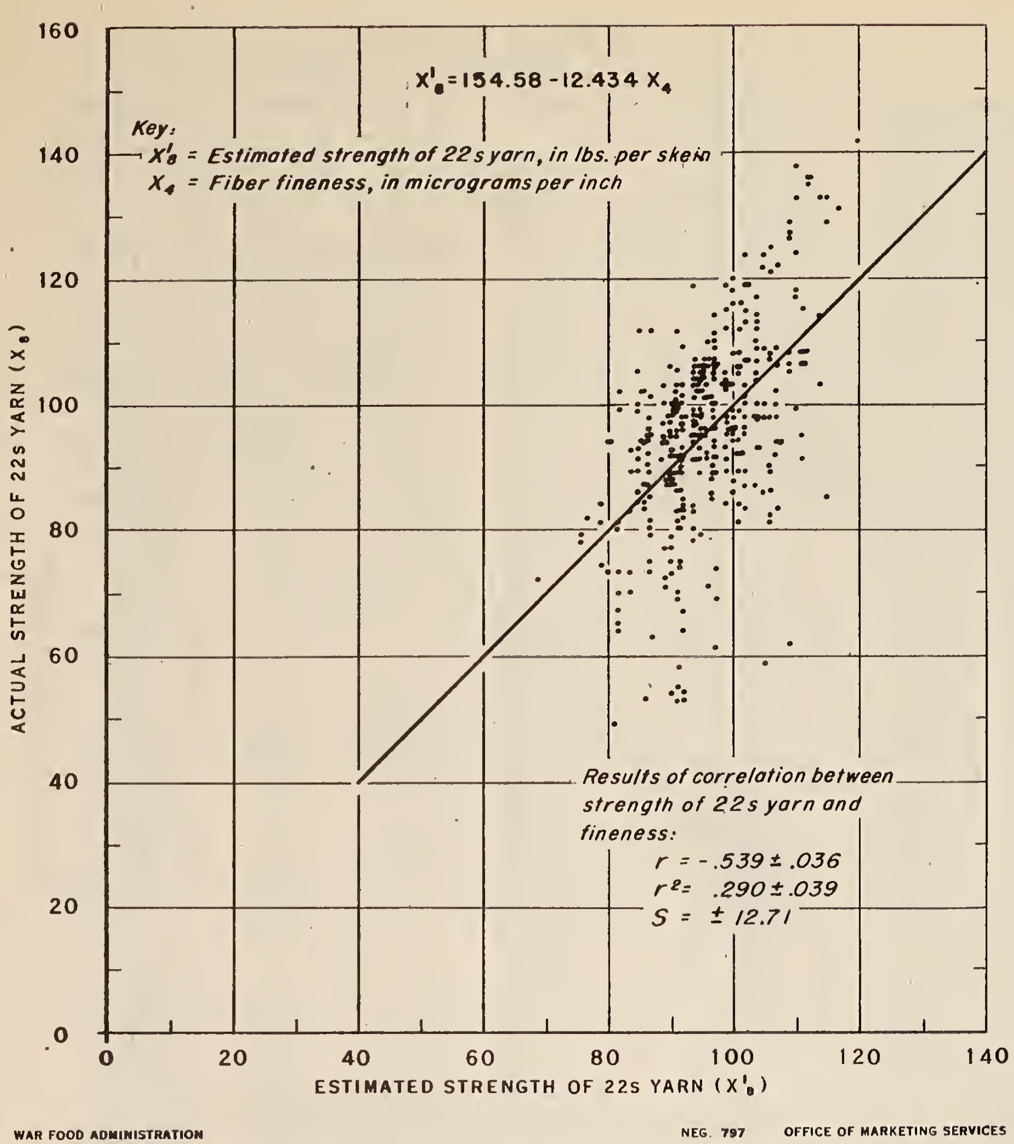

FIGURE 9—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (30) Derived From Simple Correlation

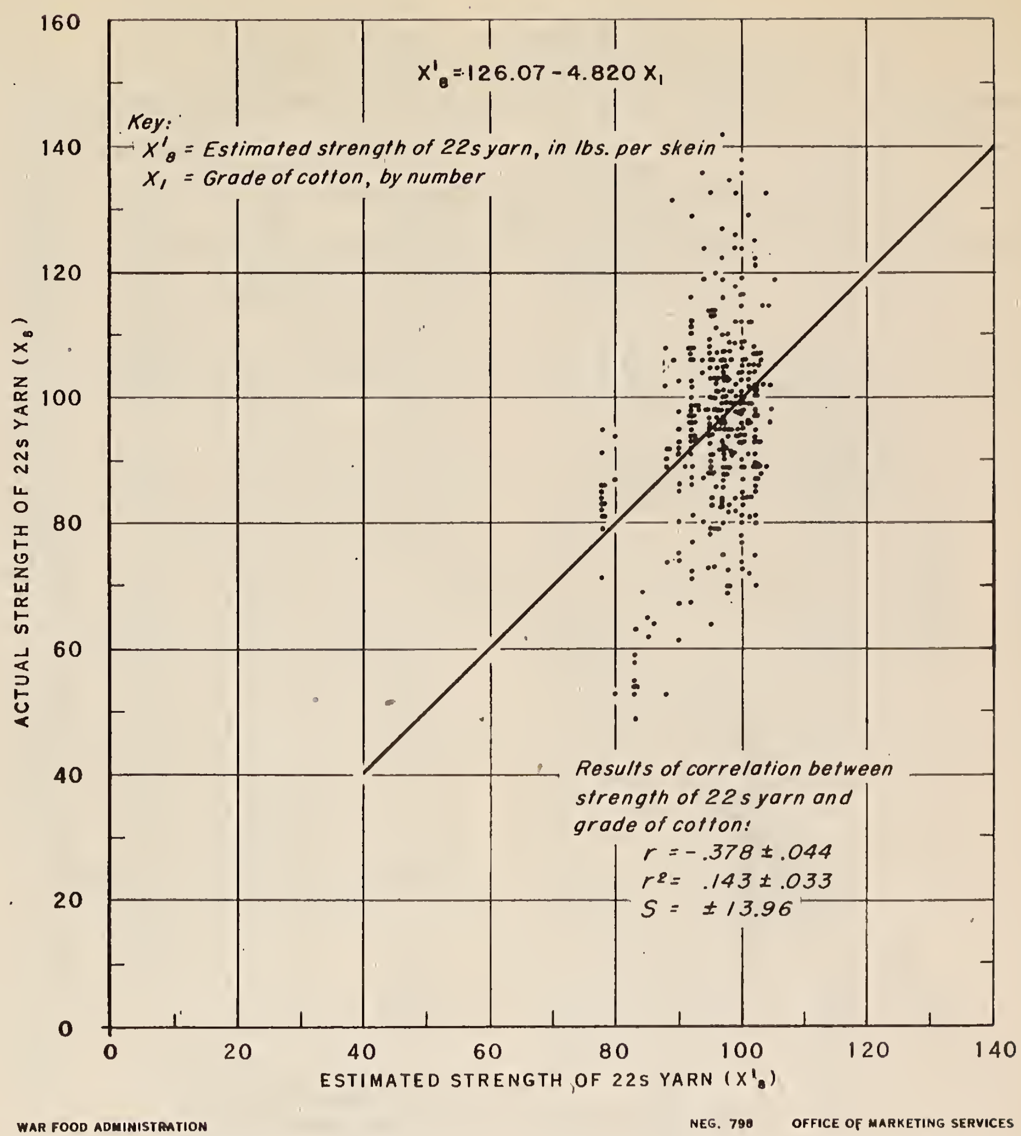

FIGURE 10—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (31) Derived From Simple Correlation

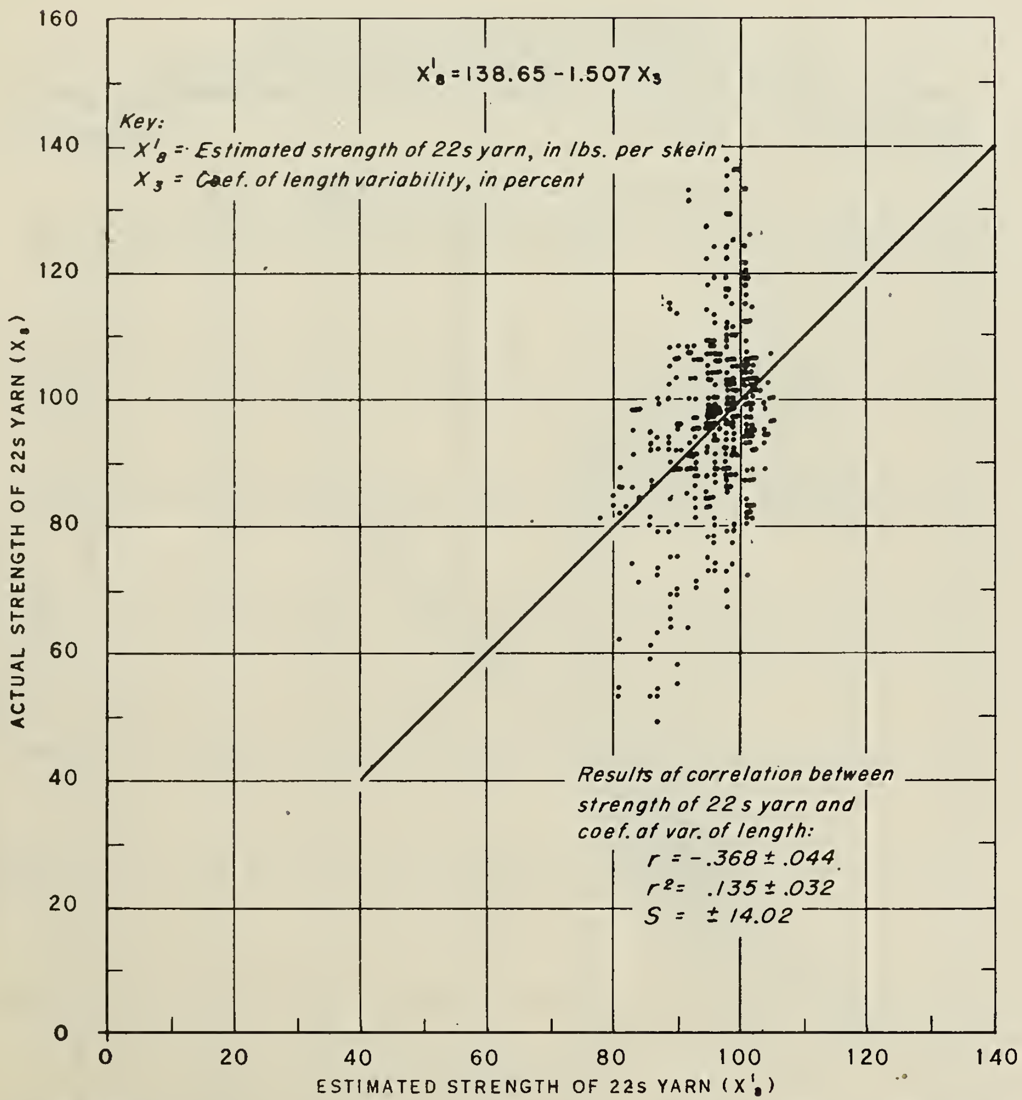

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FIGURE 11—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (32) Derived From Simple Correlation

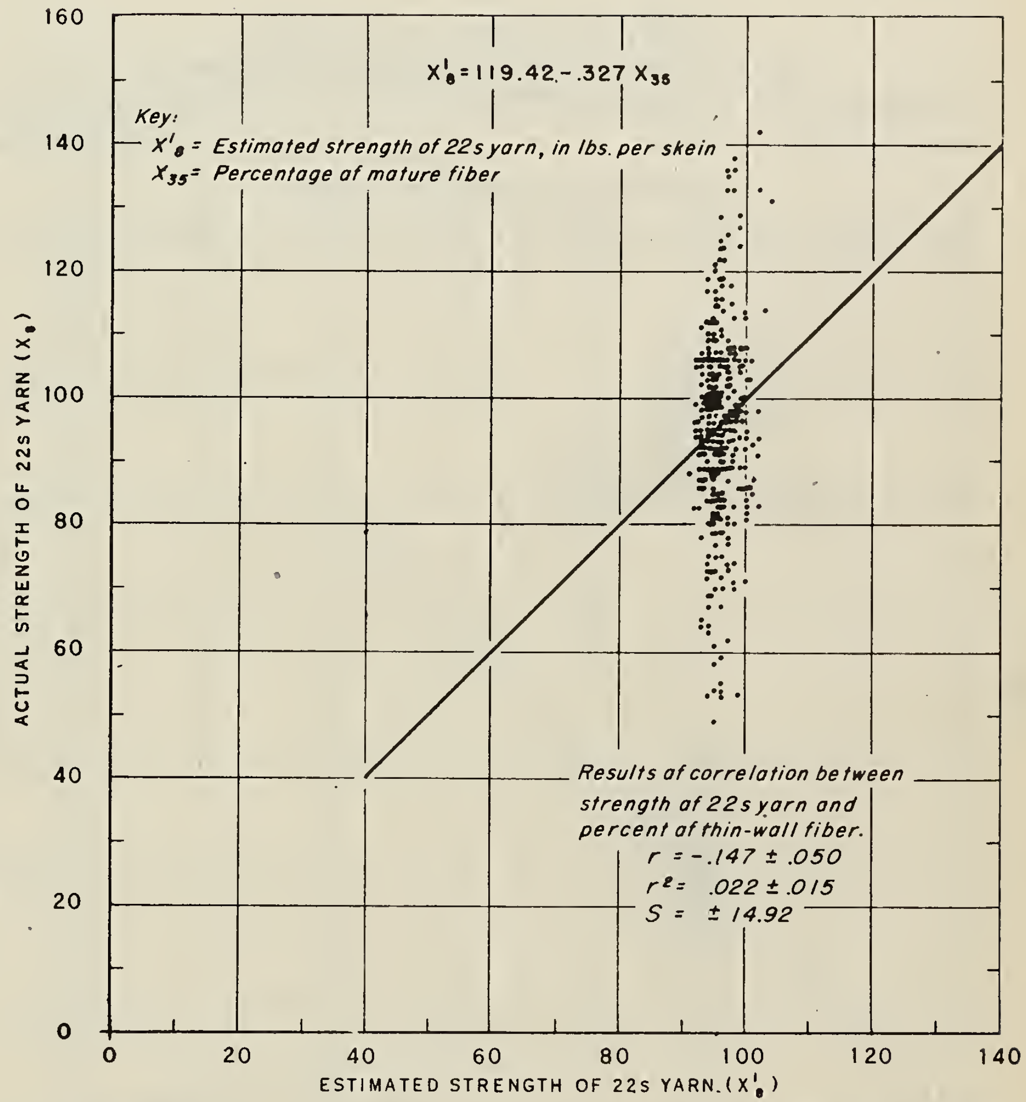

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FIGURE 12—Comparison of Actual Strength of 22s Yarn with Estimated Strength of 22s Yarn Based on the Equation (33) Derived From Simple Correlation

APPENDIX

EXPLANATION OF CERTAIN STATISTICAL TERMS, MEASURES AND METHODS USED IN THIS STUDY

The statistical methods and terms employed in this study are described in the various text books, some of which are listed below as: 13/, 14/, 15/, 16/, 17/, 18/. For convenience and ready reference to those who are not familiar with these matters and who may not have access to such text books, brief descriptions of the more pertinent items are given herewith.

The dependent variable used in these studies is represented by the symbol X_8 in the case of the strength of 22s carded yarn and by the symbol X_{16} in the case of the strength of 60s yarn. The magnitude of each of these variables depends upon the magnitude of the various properties of the fibers composing the yarn, hence its designation as the dependent variable. When the symbols are primed, as X_8' and X_{16}', they represent the estimated strength of 22s and 60s yarn, respectively, as calculated from a regression equation involving one or more fiber properties, or only the mean yarn strength of the series.

The independent variables are represented by X with various subscripts to indicate certain fiber properties as follows:

> X_1, grade of cotton, by number - the smaller the grade number, the higher the grade of cotton, and vice versa. When the grade is designated by name followed by a plus sign, 0.33 is subtracted from its grade number, and when the grade name is followed by a minus sign, 0.33 is added.
>
> X_2, upper quartile length in inches, as determined by the Suter-Webb sorter. It is the length at the 25 percent point, reading from the longest fibers, or that length at which 25 percent of the fibers by weight in the sample are equal to and longer.

13/ Statistical Methods Applied to Economics and Business, by Frederick Cecil Mills. Henry Holt and Company, New York. Revised edition, Dec. 1940.

14/ Practical Business Statistics, by Frederick E. Croxton and Dudley J. Cowden. Prentice-Hall, Inc., 1941.

15/ Methods of Correlation Analysis, by Mordecai Ezekiel. 2nd edition. John Wiley and Sons, Inc., 1941.

16/ The Combination of Observations, by David Brunt. Cambridge. The University Press, 1923.

17/ Application of a Simplified Method of Graphic Curvilinear Correlation, by L. H. Bean. Published by the Bureau of Agricultural Economics, U. S. Department of Agriculture, 1929. (Mimeographed.)

18/ See footnote 11/, p. 40.

X_3, coefficient of length variability, in percent. This measure indicates the degree of uniformity or irregularity of the fiber lengths, it being the standard deviation of the fiber length-weight groups expressed as a percent of the mean length. The smaller this figure, the more uniform is the cotton with respect to fiber lengths, and vice versa.

X_4, fineness of fiber, as expressed in terms of micrograms per inch. The smaller this figure, the finer are the fibers; the larger this figure, the coarser the fibers (due regard being given to the percentages of mature and thin-walled fibers present).

X_{35}, percentage of mature fibers. This figure represents the relative number of mature fibers to the total number of all the fibers observed. A mature fiber is one whose wall thickness is equal to or greater than one-half the width of the lumen or cavity within the fiber.

X_6, strength of raw cotton in 1,000 pounds per square inch, as determined by breaking round, wrapped bundles of fibers, according to the so-called Chandler method.

X_{10}, staple length of cotton in inches, as determined by classing specialists of the Appeal Board of Review Examiners, USDA.

X_{11}, mean fiber length, as based on results obtained with the Suter-Webb sorter, using weight-percent frequency for fiber-length distribution.

The simple correlation coefficient is represented by the symbol r. Its value indicates how closely 2 variables are associated with each other, $\pm$ 1.00 being perfect correlation and zero being no correlation. Whether plus or minus, a correlation coefficient of 0.90 and above is considered very good; 0.80 to 0.89, good; 0.60 to 0.79 fair; and below 0.60, poor. A plus sign before the coefficient of correlation indicates a positive correlation between the 2 variables under consideration; a minus sign indicates a negative correlation.

A method of judging the reliability of the correlation coefficient is to determine its standard error and compare this with the correlation coefficient. Statisticians usually have considerable confidence that the relationship is not a result of chance alone if the coefficient of correlation (r) is at least 3 times its standard error.

The multiple correlation coefficient is represented by the symbol R with or without subscripts. When followed by a subscript, the figure to the left of the period indicates the dependent variable and those to

the right, the independent variables used in the analysis. This statistical value indicates the closeness of the combined effect of 2 or more fiber properties on the strength of yarn, the closeness of association being judged by the same criterion as for simple correlation. Unless otherwise stated, linear correlation is to be understood. Usually no sign is attached to the multiple correlation coefficient.

The coefficient of determination r^2 or R^2 is the square of the coefficient of correlation. When r^2 is used, simple correlation is involved and, when R^2 is used, multiple correlation is involved. The subscripts correspond to those of the correlation coefficients. The magnitudes of the values indicate the proportion of the total variance in the dependent variable, yarn strength in this case, which is accounted for by the variable or variables being considered, as indicated by the subscripts shown. Thus, a value of 0.423 for r^2 or 0.871 for R^2 signifies that 42 percent of the yarn-strength variance is accounted for by the particular independent variable or single fiber property used and that 87 percent is the amount of the yarn-strength variance that can be explained by the several independent variables or fiber properties considered collectively.

The standard error of estimate S, frequently referred to as the standard error, indicates the range within which the observations would be expected to differ from the estimated values in two-thirds of the cases as based on the regression line or line of average relationship. The formula used was $S = \sigma X_8 \sqrt{1 - r^2}$ or $S = \sigma X_8 \sqrt{1 - R^2}$, and the values obtained were checked by calculations based on actual deviations from the regression line.

The standard deviation is used to indicate the variability of the observations. In a so-called normal distribution, approximately two-thirds of the observations will fall within $\pm$ this value from the mean of the observations. This is the same as the standard error of a single observation. When σ is modified by a subscript such as illustrated by σr, the value indicates the standard error of r. If r is greater than 3 times σr, the value of r is considered to have significance. The standard error of r is calculated by the formula $\sigma r = \frac{1 - r^2}{\sqrt{N}}$ and the standard error of r^2 by the formula $\sigma r^2 = 2r\, \sigma r$. The formula holds for both simple and multiple correlation. The square of the standard deviation is called variance.

The regression coefficients b indicate the units of change in the dependent variable corresponding to a unit change in the independent variable. They represent values appearing in the equations as a multiplier to a value represented by the symbol X with a subscript. The b generally appears with several subscripts, the first one on the left indicating the dependent variable and the second, the independent variable or fiber property to which the coefficient is attached. These are followed by a period. The other subscripts indicate the other independent

variables or fiber properties included in the analysis. The standard errors of the b's are obtained in connection with the solution of the normal equations.

The coefficients of partial correlation. Several statistical measures are available for determining the importance of an independent variable in terms of its relation to a dependent variable. Of these measures, each of which has certain advantages and disadvantages, the coefficient of partial correlation is considered the most reliable because of the fact that it measures how much a particular independent variable reduces the variance of the dependent variable, after the effects of all the other variables included in the equation have been taken into account. In this instance, the coefficients of partial correlation refer to how much each of the six fiber properties considered reduces the variance in skein strength of 22s and 60s yarn, respectively, after the effects of the other five fiber properties included in the equation have been taken into account. Thus, this measure differs radically from the simple correlation coefficient, where the effects of all the fiber properties, except the one in question, are disregarded in the analyses.

Partial correlation coefficients are indicated by the symbol "r", with subscripts. The subscripts correspond to those of the regression coefficients and indicate the variables or fiber properties involved. Those on the left of the period represent the two variables whose association is measured while the others represent the remaining variables entering in the analysis. For example, the formula to determine the partial correlation coefficient for fiber strength in relation to strength of 22s yarn is $r_{86.1234(35)} = \sqrt{b_{86.1234(35)}\,(b_{68.1234(35)})}$. The calculations were subsequently checked by mathematical computation based on the definition of the partial correlation coefficient by using the results from the correlation analysis with 6 fiber properties and those for 5 fiber properties, where each of the 6 fiber properties is omitted in turn. For example, the formula to determine the partial correlation coefficient for fiber strength in relation to strength of 22s yarn is $r_{86.1234(35)} = \sqrt{\dfrac{R_{8.1234(35)6} - R_{8.1234(35)}}{1 - R_{8.1234(35)}}}$. The latter method has certain advantages over the former in that it is applicable to curvilinear correlation as well as linear and, also, in that it is applicable to partial correlation with respect to the importance of two or more fiber properties in combination, whether linear or curvilinear correlation is involved.

The coefficients of partial determination are indicated by r^2 with subscripts corresponding to those of the partial correlation coefficients. This measure represents the square of the coefficient of partial correlation but it possesses limitations, since the sum of those included in an analysis may be greater than 1.00 due to the fact that different bases are involved, as a result of different denominators being used in the calculations. The coefficients of partial determination have been calculated but they are not reported in this paper.

The beta coefficients B, with subscripts similar to those for the regression coefficients, constitute another method for indicating the relative importance of the respective variables or fiber properties to the dependent variable or yarn strength. These measures indicate the change in terms of units of standard deviation of the dependent variable resulting from a change of one standard deviation in the independent variable or fiber property under consideration. They are not, however, comparable as between different sets of data or groups of cottons. In simple correlation, the value of the beta coefficient and that of the correlation coefficient are identical. There is a tendency on the part of some to use the beta coefficient instead of the partial correlation coefficient, primarily because so much less time and work are required in the calculations, especially when more than 3 variables are involved. However, a great deal in accuracy of results and conclusions may be sacrificed by so doing. The values for the beta coefficients have been determined in this study but they are not reported in this paper.

The coefficients of separate determination d, with subscripts similar to the regression coefficients, are used as still another method for indicating the contribution of variance attributed to each independent variable or fiber property. The algebraic sum of these coefficients is equal to the multiple coefficient of determination, and this is a desirable feature. However, the fact that occasionally a negative coefficient of separate determination occurs has led to some question as to the reliability of this statistical measure. The values for the coefficients of separate determination have been calculated in this study but they are not included in this report.

Regression equations are derived by methods described in various text books on statistics, some of which are listed earlier in the Appendix. The equations show the relation between 2 or more variables. In this instance, such equations reveal the relation existing between one or more fiber properties and the strength of yarn, as well as the relation between any pair of fiber properties considered. The equations are expressed in symbolic form and consist of one or more regression coefficients multiplied by one or more symbols representing the magnitude of a fiber property, and a term called a "constant."

Use of regression equations. The fiber-yarn equations presented provide a tool for directly predicting or estimating the skein strength of 22s or 60s yarn from a knowledge of the magnitude of the various fiber properties. To illustrate the use of these equations, the magnitudes of the fiber properties for one of the cottons used in this study are as follows:

X_1,	grade of cotton, by number	5.00
X_2,	upper quartile length, in inches	1.16
X_3,	coef. of length variability, in percent	28.00
X_4,	fiber fineness, in micrograms per inch	4.80
X_{35},	percentage of mature fibers	70.00
X_6,	fiber strength, 1,000 lbs. per sq. in.	89.00

The values listed previously are substituted in the appropriate equation. If the estimated strength of 22s yarn is desired and if six fiber properties are included, equation (2), as shown in table 4, should be used.

The values substituted in this equation give the following results:

$$(2)\ X_8' = 106.85000-1.894\ (5.00) + 31.836\ (1.16) -1.939\ (28.00) -7.318\ (4.80) -0.264\ (70.00) + 0.942\ (89.00) = 110.2$$

The estimated yarn strength of 110.2 pounds, as calculated above, compares with 104.0 pounds for the value obtained by actual test.

The factors and the constant are set up so that five decimal places will result in all the products. This is done so that the calculation may be made by cumulating these products on a calculating machine, then adding or subtracting the constant term according to its sign. In several cases the products are multiplied negatively. Such a procedure represents a considerable saving of time when a large number of estimates are involved.

Use of regression equations and conversion formula. The regression equations for estimating 22s and 60s yarn strength also may be used for estimating yarn-skein strength of other counts through conversion of the results so obtained by means of the formula previously referred to in circular 413 19/. The formula is as follows:

$$S_2 = \frac{C_1 S_1 - (C_2 - C_1)\ 21.7}{C_2}$$

In which C_1 = 22 or 60 (depending upon whether the fiber property equation for 22s or 60s yarn is used)

C_2 = the count desired

S_1 = the estimated value obtained from a fiber-property equation for 22s or 60s yarn

S_2 = the estimated strength of the desired count

The procedure to follow is to estimate directly the strength of either 22s or 60s yarn by substituting the known fiber properties in the appropriate equation, using the equation involving the yarn count that is nearest to that desired, then substituting the estimated strength value so derived in place of S_1, replacing C_1 by 22 or 60 (as the case may be) and replacing C_2 by the particular count whose estimated strength is desired. The formula is applicable to all counts of yarns between 20s and 60s and may be used to some extent for estimating yarn strength outside of this range of counts, particularly in the lower counts.

19/ See footnote 8/, p. 10.

For example, if the estimated strength for 22s yarn is 110.2 pounds, as shown in the previous illustration for direct estimation from the regression equation (2), the estimated strength of 44s yarn would be obtained by substituting in the conversion formula, as follows:

$$S_2 = \frac{22\ (110.2) - (44 - 22)\ 21.7}{44} = 44.2$$

This result compares with 41.8 pounds for the actual strength of 44s yarn spun from this particular cotton. Tables or nomographs greatly facilitate conversion of strength values from one count to another, examples of which are given in the publication describing this formula.

Scatter diagrams. Graphic charts have been prepared extensively in connection with this study but only a limited number of the more pertinent ones are included in this report. By using the direct method, the values for all possible pairs of the fiber properties have been plotted graphically against each other, as also has been done for each of the fiber properties against those for the skein strength of yarn. It is easily apparent from these two-variable scatter diagrams that certain of the fiber properties are correlated with each other and that others are not; also, that certain of the fiber properties are correlated with yarn strength while some are not. The exact degree of the association between the various pairs of fiber properties and between each of the fiber properties and yarn strength, however, is not evident from the graphs alone. This status is due to the fact that the scatter of observations and trend lines are not precisely comparable from chart to chart throughout each of the two series of graphs, since different units of measurements necessarily have to be employed with the different fiber properties.

Direct graphing or plotting of values on a single sheet is impossible in the case of three or more variables, which frequently occur in this study. By means of an indirect method, however, the degree to which relationships are present between yarn strength and any combination of 2 or more fiber properties may be graphically revealed by plotting the corresponding actual and estimated values for yarn strength against each other. That is, by using the equations developed for 2 or more fiber properties under consideration, an estimated value of yarn strength for each cotton can be obtained which reflects the combined weighted effects of all the fiber properties and combinations considered. The estimated value of yarn strength, when plotted against its corresponding actual value, furnishes a picture of what is involved with each cotton, and a series of such plotted dots graphically reveal what is associated with a group of cottons.

The vertical and horizontal scales are identical in each and every chart of this type, thus making possible direct and easy graphic comparison of the precision of the relationships expressed by all the equations.

By applying this indirect method of plotting in cases where only one fiber property in relation to yarn strength is involved, as well as where 2 or more fiber properties are concerned, pictorial comparisons may be made of all segments of results obtained throughout an entire series, even though varying numbers of fiber properties are included and in spite of the fact that various units of measure are necessitated by the different tests. If all the dots plotted on such charts should fall on the 45° line drawn in any of the graphs, this would indicate perfect agreement between the estimated and actual yarn-strength values. As plotted in these instances, a dot below the line indicates that the strength of the yarn has been overestimated and a dot above the line, underestimated.

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